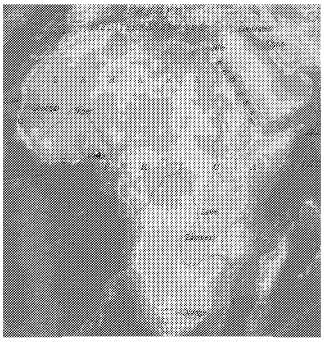
LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)
Core Project of the
International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)

and

NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION, through
GLOBAL CHANGE SYSTEM FOR ANALYSIS, RESEARCH AND TRAINING,
INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION,
THE RIJKSINSTITUUT VOOR KUST EN ZEE (COASTAL MANAGEMENT CENTER),
UNITED NATIONS ENVIRONMENT PROGRAMME, REGIONAL OFFICE FOR AFRICA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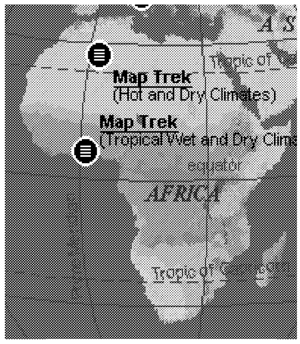

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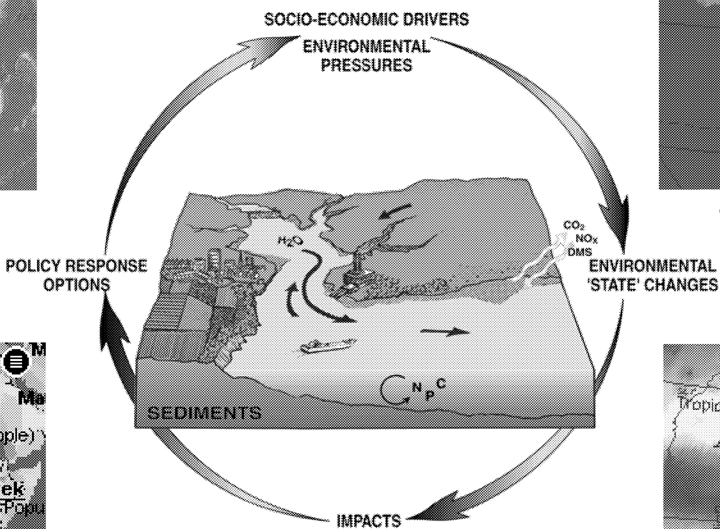

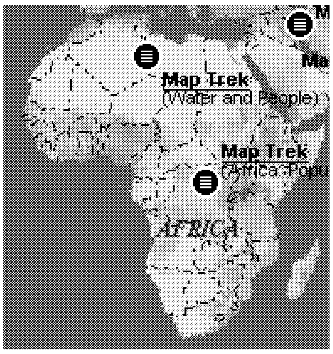

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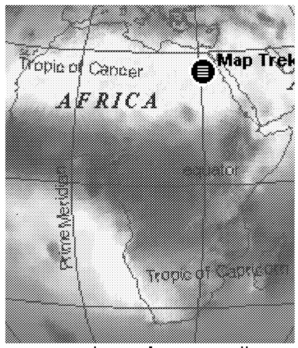

Precipitation

African Basins

LOICZ Global Change Assessment and Synthesis of River Catchment–Coastal Sea Interaction and Human Dimensions

Compiled and edited by R.S. Arthurton, H.H. Kremer, E. Odada, W. Salomons and J.I. Marshall Crossland

Ministerie van Verkeer en Waterstaat
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LOICZ IGBP
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LOICZ REPORTS & STUDIES No. 25

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by

R.S. Arthurton, H.H. Kremer**, E. Odada***, W. Salomons**** and J.I. Marshall Crossland***

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NORAD
DIREKTORATET FOR UTVIKLINGSSAMARBEID
NORWEGIAN AGENCY FOR DEVELOPMENT COOPERATION

LOICZ REPORTS & STUDIES No. 25

Published in the Netherlands, 2002 by:
LOICZ International Project Office
Netherlands Institute for Sea Research
P.O. Box 59
1790 AB Den Burg - Texel
The Netherlands
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The Land-Ocean Interactions in the Coastal Zone Project is a Core Project of the "International Geosphere-Biosphere Programme: A Study Of Global Change" (IGBP), of the International Council of Scientific Unions.

The LOICZ IPO is financially supported through the Netherlands Organisation for Scientific Research by: the Ministry of Education, Culture and Science (OCenW); the Ministry of Transport, Public Works and Water Management (V&W RIKZ); and by The Royal Netherlands Academy of Sciences (KNAW), and The Netherlands Institute for Sea Research (NIOZ).

This report and allied workshops are contributions to the global LOICZ Basins assessment and synthesis core project: The Biogeochemical and Human Dimensions of Land-Based Fluxes to the Coastal Zone.

Citation: Arthurton, R.S., H.H. Kremer, E. Odada, W. Salomons and J.I. Marshall Crossland 2002. African Basins: LOICZ Global Change Assessment and Synthesis of River Catchment–Coastal Sea Interaction and Human Dimensions. LOICZ Reports & Studies No. 25: ii+344 pages, LOICZ, Texel, The Netherlands.

ISSN: 1383-4304

Cover: The cover shows various images of Africa from MS Encarta Interactive World Atlas (1999) and the DPSIR framework cycle as shown in LOICZ R&S No 11 (from Turner *et al.* 1998).

The LOICZ Reports and Studies series is published and distributed free of charge to scientists involved in global change research in coastal areas.

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Workshops Structure
This report provides a synthesis of the contributed papers and regional investigations of the two-phase LOICZ African Basins assessment process conducted in July 2000 and October/November 2001.

Acknowledgements
LOICZ is grateful for the generous sponsorship and support for the meetings by the Global Change System for Analysis, Research and Training, START, the Norwegian Development Agency, NORAD, the Intergovernmental Oceanographic Commission, IOC of UNESCO and the local host, Regional Office of Africa of the United Nations Environment Programme, UNEP/ROA in cooperation with the Pan-African START Secretariat, PASS.

LOICZ is indebted to Professor Eric Odada and his team from PASS and the University of Nairobi, Drs Sekou Toure and Yinka Adebayo of UNEP/ROA and Dr Salif Diop, UNEP Division on Early Warning and Assessment, in dealing with the local organizational requirements needed for the successful meetings and the substantial scientific contribution that they made to the progress of the AfriBasins workshops.

These meetings set the scientific stage on regional scale for the upcoming second phase of the LOICZ project from 2003 and related LOICZ-Basins core activities in Africa. These steps will help to strengthen support for regional networks and lead the way to continued work. We thank all participants who ensured the vitality of the highly interactive meetings, and contributed to this report.

The editors wish to thank Dr Jacques Denis, of Ifremer, for his assistance with the manuscripts written in French.

1. EXECUTIVE SUMMARY

by R.S. Arthurton and H.H. Kremer

The LOICZ-Basins project

The Land Ocean Interactions in the Coastal Zone (LOICZ) core project of the International Geosphere Biosphere Project, IGBP, is evaluating the physical, biogeochemical and human interactions influencing coastal change. The coastal zone is an integral part of the water cascade between catchments and oceans that is subject to external and internal forcing from both anthropogenic and natural pressures. LOICZ has four foci, under which there are three categories of projects. The LOICZ-Basins project is working to assess at local to global levels the impacts on the coastal environment of changes caused by such pressures and drivers within river catchments. Drivers such as damming, deforestation, agriculture and urbanisation influence the flows of water, nutrients, sediments and pollutants to the coastal sea. Studies addressing these issues have produced large amounts of data, but generally these data have not been subject to integrated assessment and synthesis. Only recently have the interactions of human historical evolution and biogeochemical environments been considered.

In LOICZ-Basins a river catchment (or island) and its associated coastal area are treated as one system (Figure 1.1). The focus is on the horizontal fluxes of substances within this system. This approach, integrating the natural and social sciences, addresses issues such as critical concentrations and loads, biological resilience and carrying capacity. To generate a global picture, a set of standardised (and thus comparable) regional assessment workshops has been implemented, using an adaption of the Driver-Pressure-State-Impact-Response (DPSIR) framework, developed by the OECD (see Appendix 1). The assessment aims to up-scale information from individual river catchment-to-coastal sea systems to sub-regional, then regional, levels. Characteristic types of coastal issue and change are identified and prioritised, and linked to their perceived major drivers.

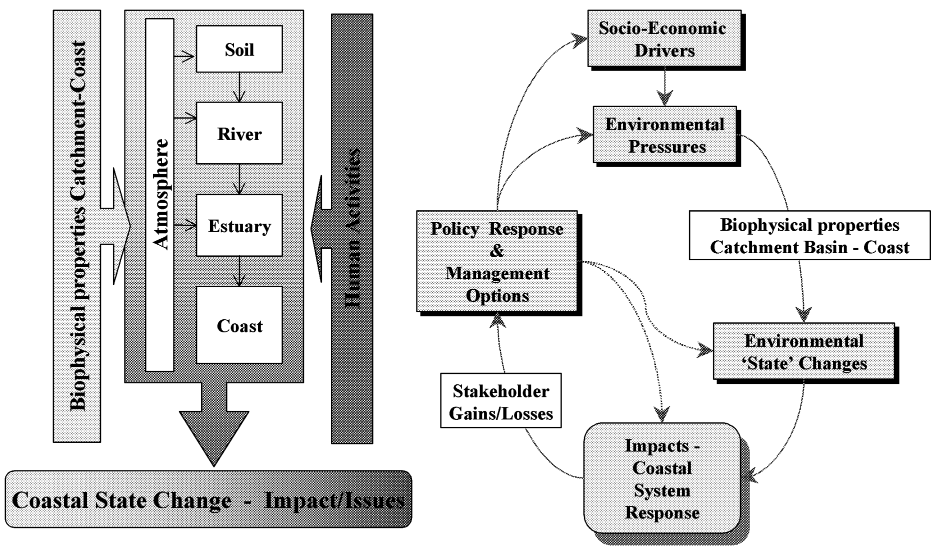


Figure 1.1 The catchment (island)-coastal zone system and the DPSIR framework.

LOICZ-Basins contributes directly to UNEP's Integrated Coastal Area and River Basin Management initiative (ICARM) as well as UNESCO/IOC Integrated Coastal Area Management (ICAM) and Coastal GOOS (Global Ocean Observing System) programmes. Links with other global projects including the Global International Waters Assessment (GIWA), with which LOICZ-Basins has some common interests, have been established.

The African Basins (AfriBasins) workshops

Two workshops were held in Africa to address LOICZ-Basin issues. The introductory workshop (AfriBasins I) was held at the UNEP headquarters at Gigiri, Nairobi, Kenya and hosted by the Regional Office for Africa (ROA) in July 2000. The second workshop (AfriBasins II, also in Nairobi, Oct/Nov 2001, and hosted by ROA) refined the preliminary assessments and focused on human dimensions. A principal objective was to highlight at local to regional scales the linkages between human activity drivers in the catchments and environmental and socio-economic issues and impacts in the coastal areas. Using this information, a second objective was to establishi a sound basis upon which to develop proposals for interdisciplinary case studies on the human dimensions of land-driven coastal change within the African region, with a focus on the implications for coastal monitoring and management. For this purpose "hot spots" important for future research evaluation and a project design applicable to various spatial and temporal scales was to be identified. The workshop considered a draft "AfriCat" proposal, developed from the on-going "EuroCat" project, as an umbrella for the case studies. The proposal would have an emphasis on addressing the regional African needs, in the context of the priority areas for action as identified by the African Ministerial Conference on the Environment (AMCEN) in preparation for the World Summit on Sustainable Development in Johannesburg, September 2002.

Overview of the African catchment–coastal zone system

Building upon the output from AfriBasins I, eight sub-regions were identified for assessment within the Africa region, on the basis of geomorphological and climatic characteristics (Figure 1.2). The various sub-regions differ widely not only in the biophysical nature of their catchments but also in the availability and quality of existing data relating to their material fluxes. The named catchments assessed (Figures 1.3 and 2.1) were chosen as representative of their respective sub-regions.

1. North West Africa – relatively arid, medium basins (Sebou, Moulouya) with seasonal runoff and (in Morocco) major human pressure through diversion and damming causing coastal change issues; includes coastal stretches of Algeria and Tunisia but no information on systems there was gathered during the AfriBasins process.
2. West Africa – featuring a variety of large, transboundary (Niger, Volta, Senegal) basins subject to major damming resulting in reduced sediment and water fluxes and reduced coastal stability as a growing threat to the lagoon-based cities; also the medium basin of the Cross River. Damming, deforestation and agriculture are considered to be the principal drivers of state changes at the coast through modifications of the hydrological regime, water quality and sediment discharge in the large catchments.
3. Congo – a sub-region with extensive, though diminishing, rainforest. Available information about its land-based drivers and how they relate to coastal issues is scarce. The large transboundary Congo basin has little variation in discharge through the year.
4. South West Africa (Cape to southern Angola) – mostly dominated by the upwelling system of the Benguela current; cool and temperate small (Berg) and medium (Olifants) catchments in the south, arid large catchment (Gariep, formerly Orange) in the north with limited river runoff. Damming and agriculture are the principal drivers considered responsible for minor-to-medium but progressive state changes and impacts at the coast, causing modifications to runoff, water quality and coastal geomorphology.

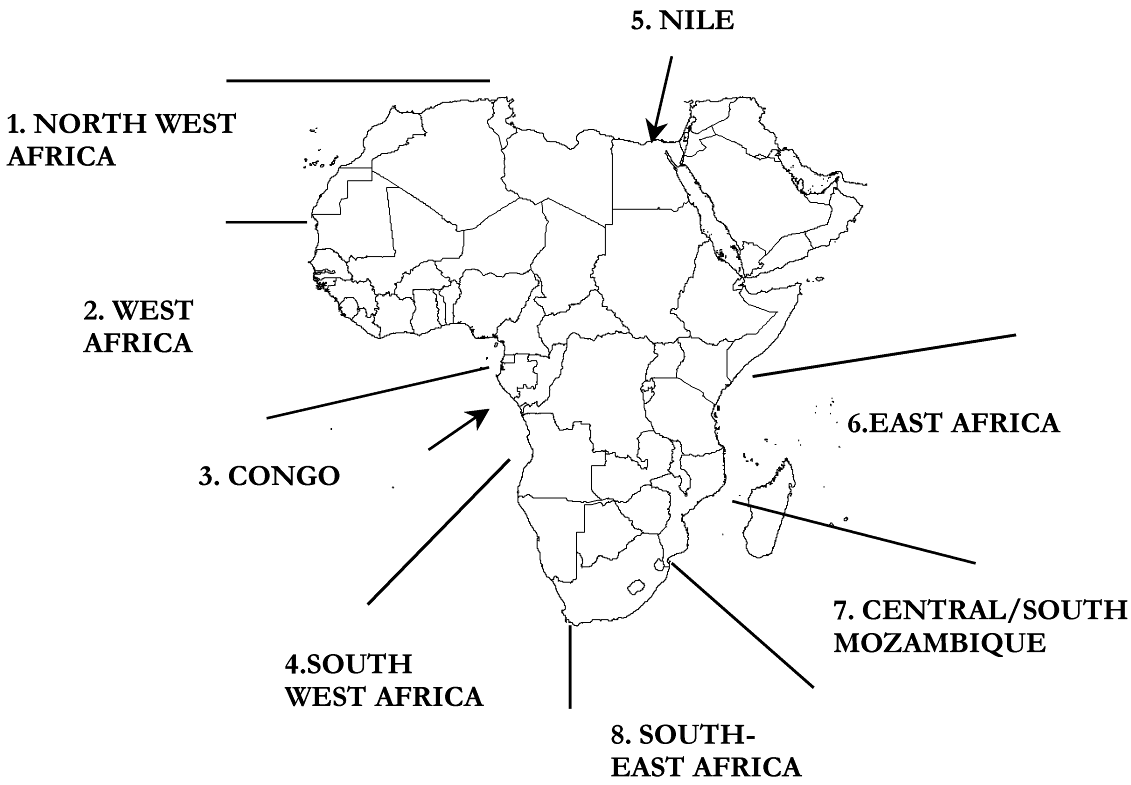


Figure 1.2. Sub-regions for the assessment of river catchment-coastal sea interaction classes determined in the LOICZ AfriBasins workshops.

5. Nile – a single-catchment sub-region incorporating the wider coastal stretches influenced by the Nile catchment with land-based drivers including the Aswan dam, urbanisation and agriculture. The damming of this transboundary river system has led to profound changes in fluxes through the Nile delta and in the associated coastal sea (the Mediterranean). This is exacerbated by a rapid growth of urbanisation and industrialisation around Cairo and changes in agricultural practice in the Nile River valley and its delta region.

6. East Africa (Somalia to northern Mozambique) – featuring medium (Tana, Sabaki, Rufiji) and small catchments with monsoonal (seasonal) flushing and subject to damming; also extensive coral reefs. Coastal erosion and sedimentation, pollution and loss of biological functioning are the principal impacts. Damming, deforestation and agriculture are the principal drivers and these are expected to become increasingly significant in respect of their impacts.

7. Central/south Mozambique – medium (Incomati) and large, transboundary (Zambezi, Limpopo) catchments with high seasonality in runoff and subject to extreme cyclonic events; an estuarine/deltaic coast characterised by beach plains and mangrove-fringed creeks. The principal issues are reduction in stream flow, coastal erosion, salinisation and nutrient depletion, all attributed to damming.

8. South East Africa – ranging from subtropical in the north to warm temperate on the Cape coast and characterized by medium (Thukela, Great Fish) and small (Groot Brak, Kromme) catchments that are subject to various anthropogenic pressures, particularly water abstraction. Damming is an important driver, with freshwater retention in semi-arid conditions, and there are plans in place for further intensive damming.

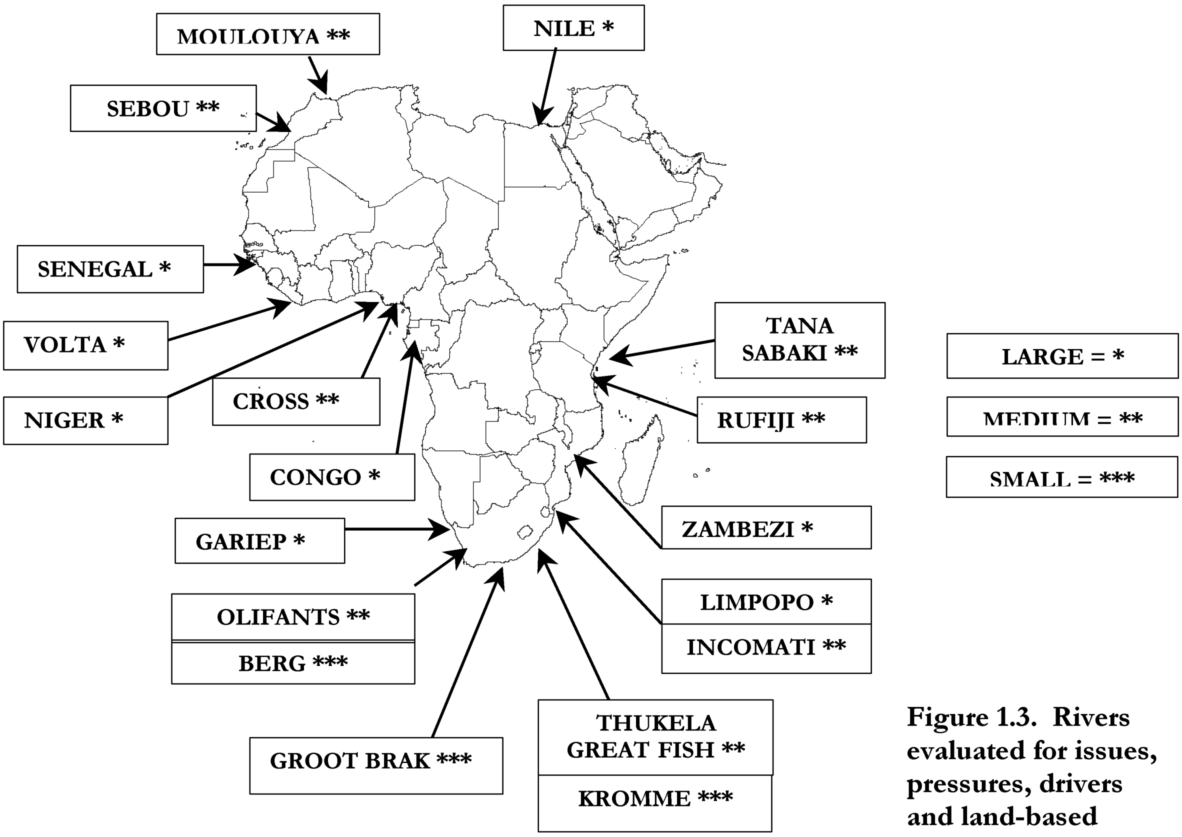


Figure 1.3. Rivers evaluated for issues, pressures, drivers and land-based activities in the AfriBasins II.

Impacts and state changes and their future trends

For the Africa region a prelimimnary ranking order was drawn up together with expected future trends in impacts (Table 1.1).

Table 1.1 Major activities (drivers) and present status and trends affecting the coastal zone in Africa.

Anthropogenic drivers	Major state changes and impact	Present status	Trend expectations	Major areas affected
Damming Diversion	Erosion Sedimentation	Major	Increasing	Almost all sub-regions, with 2 and 5 as particular "hot spots"
	Salinisation	Local	unknown	1, 7
	Nutrient depletion			7, 8
Various drivers	Biodiversity loss	Major		Almost all sub-regions
Deforestation	Erosion Sedimentation			Medium ranking for most sub-regions, but major for coastal impact generated in small and medium catchments in 1 and 6
Agriculture				
Urbanisation	Eutrophication Pollution	Medium	Increasing	Medium overall but major in 5
Industrialisation	Pollution			As above, but in most cases more coastal than catchment-based – 4 , 5, 6

Coastal erosion and sedimentation were identified as significant and progressive impacts in nearly all of the sub-regions, the problems being acute in the Nile delta and West African lagoon systems. Damming was viewed as the principal driver, with reductions in stream flow and sediment flushing. Damming also contributed to estuarine salinisation, e.g., the Incomati River in Mozambique, and nutrient depletion in the coastal sea, e.g., off KwaZulu Natal. In most sub-regions deforestation and agriculture were regarded as important drivers, particularly in respect of coastal sedimentation from medium and small catchments, e.g., the Tana and Sabaki rivers in Kenya. Human settlement was identified as a major contributor to eutrophication and the proliferation of aquatic weeds in the large West African catchments. Elsewhere, while eutrophication and pollution were recognised, they were mostly restricted to local (coastal) urban-industrial sources, e.g., Alexandria, Mombasa, Saldanha Bay and Cape Town. Loss of biodiversity or biological functioning was seen as another common issue, related to a complex interplay of human and natural drivers.

In general these data are characteristic of developing economy situations where economic growth and water use exceed the development of the necessary urban and industrial infrastructure. This finding parallels those made in the South American (SAmBas), and East Asian Basins assessment and synthesis processes (Lacerda *et al.* 2001; Hong *et al.* in prep.). However, heterogeneity of the sub-regions seems to be more pronounced in Africa than in the other world regions, making the ranking of issues and drivers in Africa a more complex challenge.

The AfriBasins assessment process

In the preparation and execution of AfriBasins II, the standardised LOICZ-Basins assessment tables (Appendix 1) were used to guide the following sequence of assessment steps:

- Assessing and ranking coastal **issues/impacts** (together with their critical thresholds) due to human activities within catchments based on documented coastal changes.
- Assessing and ranking major catchment-based **drivers** and their consequent environmental **pressures** impacting the coast.
- Assessing and ranking the various **driver/pressure** settings generating the coastal **issues/impacts** and identifying the trends of **state** changes in the coastal environment; up-scaling to sub-regional then regional levels.
- Assessing and synthesising scientific, policy and/or management **responses**.
- Assessing and synthesising gaps in understanding, "hot spots" and research needs.

The issues were assessed for the rivers shown in Figures 1.3 and 2.1. A summary of the major concerns arising from the assessment is presented in Table 1.2.

A scarcity of relevant standardised data is a recurrent problem in most of the sub-regions assessed. This shortcoming applies both to scientific data and, particularly, to socio-economic information, whether concerning activities in the catchments or impacts at the coast. Time-series data generated from routine monitoring programmes is particularly sparse. The workshops highlighted a considerable dearth of knowledge about the critical loads and thresholds of material fluxes passing from the catchments to (or through) the coastal area to the coastal sea that, if exceeded, would significantly change the coastal environment. There was a need for common parameters to be established in respect of the indicators of change that were relevant to the region.

Supposed "multi-driver" impacts posed a major research challenge, particularly in the medium and large, transboundary catchments. The specific contributions (positive or negative) arising from, for example, agricultural practices, deforestation and damming to the fluxes of water and sediment that reach the coast need especially careful analysis, bearing in mind the socio-economic implications of regulation in these areas. In the AfriBasins process the rates of changes in the coastal environmental state resulting from catchment-generated pressures were assessed only in general terms – 'direct' or 'progressive'. In some cases there was uncertainty in the assessment. In order to prioritise appropriate responses in the catchments at management and policy levels, there is a need for more specific information on the rates of change as well as the time-lags between the incidence of anthropogenic pressures and the corresponding changes in the state of the coastal environment.

In addition to the material fluxes generated or influenced by human activities in the catchments, the coastal sea of the region also receives significant nutrient and pollutant discharge from the urban-industrial nodes at the coast itself. Research is needed to assess and quantify the impacts of such coast-generated pollution and eutrophication for comparison with the impacts ascribed to catchment drivers. The contributions that natural drivers make (or have made) to changes in the state of the coastal environment over a range of time-scales is another area for consideration by regionally integrated research. Understanding natural processes and their variability over time (e.g., short- and long-term climate change), as they affect both the catchments and the coast, is an important prerequisite for an assessment of the contribution that human activities may make to coastal change. The coastal impacts of human activities in catchments need to be set in the context of natural driving forces in the African context.

While the working groups accepted the various difficulties implicit in the AfriBasins assessment process, the input to the assessment tables and the conclusions drawn from them represent their expert judgement, making the best of the data available.

The AfriCat proposal
From the results of the DPSIR assessment, the workshop identified a number of river catchments within the region that were appropriate for detailed case study, examining various aspects of the catchment driver - coastal impact linkage. Such initiatives would become the input to the planned AfriCat proposal envisaged as providing a conceptual umbrella for the individual proposals to be developed by the LOICZ AfriBasins scientist network. AfriCat's broad principles would be similar to those of the established EuroCat programme (http://www.iia-cnr.unical.it/EUROCAT/project.htm).

The selection of demonstration sites provides coverage of the key issues identified by the AfriBasins workshops and also a representation of the various sub-regional river-coast classes. Many of the chosen catchments are large – greater than 200,000 km^2 – and extend over several countries, thus involving a range of transboundary issues. In each case study there would be an integrated, systematic approach to the understanding of the water cascade, taking the catchment and coast as a single system. There would be emphasis on robust science and relevant data-building and communication. It was recognised that the studies must add value to existing work, and have a strong socio-economic input, showing how the needs of a clearly identified user community were being addressed. As well as serving local and regional needs, the integrated studies of AfriCat will also feed the global aims of Earth System Science, through provision of reliable bases for up-scaling in a region where, compared with Europe for example, recent and reliable data are scarce.

Within the AfriBasins network, the key contact persons identified for each of the case study sites agreed to assist in further developing specific research proposals and to investigate the options for potential funding on national and international levels. The workshop reiterated that, regardless whether national or international financial support was targeted, the initiative and detailed networking needs at site level would need to come from the regional scientific community. LOICZ could provide a framework and assist in sustaining the necessary links.

The workshop affirmed the need for effective sub-regional coordination and a scientific coordinator for each study site, working under the general guidance of a Policy Advisory Board. The overall coordination of the further drafting process was dedicated to the Centre of African Wetlands, Ghana and the Pan African START Secretariat. UNEP-ROA confirmed its support in generating the national, governmental approval for the initiative through the AMCEN process. AMCEN was identified as an appropriate platform to facilitate the governmental approval for the various site study plans in a broader context of the Abidjan Declaration.

Demonstration sites (see Table 1.2)
For the eastern side of the region, the inclusion of the Nile was confirmed; also the Tana and Sabaki rivers as a linked site, the Rufiji, the Zambezi and the Incomati. For the Incomati site, the study could be built on earlier assessment and planning efforts conducted at the University Eduardo Mondlane in Maputo and a draft trilateral project plan between Mozambique, South Africa and Swaziland, all of which were developed with support of the Coastal Management Centre of RIKZ in the Netherlands. A project on the integrated evaluation of riverine fluxes to the Maputo Bay region, "Catchment2Coast" recently funded by the

European Commission, could be associated with the AfriCat project. This could be a key exercise in a continued second phase of the global LOICZ programme. For the western coast six sites were confirmed as providing suitable case study opportunities for AfriCat – the large catchments of the Congo, Niger, Volta and Senegal, the medium Cross, and two medium catchments in Morocco.

Table 1.2 Suggested demonstration sites* for key case studies of catchment–coastal sea systems in Africa.

Area/sub-regions	Major rivers	Regional characteristics and major coastal issues	Major drivers	Comments	Contact person(s)
West Coast					
1. North-west Africa	Moroccan catchm'ts	Semi-arid climate, small to medium catchments, high seasonal runoff variability, coastal erosion/sedimentation, salinisation	Damming Agriculture	Good coverage of flux data within catchments, few comprehensive studies on coastal linkage. Socio-economic profiles and analysis to be integrated	M. Snoussi
2. West Africa	Senegal, Volta, Niger, Cross	Transboundary catchments under strong human influence, coastal erosion, changes in nutrient supply and habitats due to changes of material transports	Damming Deforestation	Fair coverage of biogeochemical data, socio-economic information expected to be limited; baseline project development (Volta - PDF-B status).	I. Diop, A. Kane, G. S. Umoh, O. Martins, C. Gordon
3. Congo	Congo	Nutrient input	Uncontrolled urban growth	Apparently very limited data	tba
North-east Med. and East Coast					
5. Nile	Nile catchment and delta, Alexandria city coast	Transboundary river under extreme anthropogenic influence, flux changes to the floodplains and delta – high waste load	Damming, intensive agriculture, high population density	Good data coverage Add integrative value to existing projects	H. Awad
6. East Africa	Tana/ Sabaki	Monsoonal runoff with sediment load changes	Damming, agriculture	Holistic study, flux data generation	J. Kitheka, J. Ochiewo
	Rufiji	Monsoonal discharge through mangrove to Mafia marine park with coral reefs	Agriculture, high population density	Flux data generally very limited	A. Ngusaru
7. Central/south Mozambique	Zambezi	Large transboundary catchment with the largest reservoir in Africa, discharge to delta/beach plain coast	Damming	No comprehensive study available; investigations would partly have to generate data	T. Forbes, L. Mhlanga
	Incomati	Transboundary catchment with major erosion and salinisation impacts, medium eutrophication and biodiversity loss	Damming Agriculture Urbanisation	Reasonable data coverage, earlier assessment and project development carried out	A. Hoguane, F. Tauacale
	Maputo Bay (incl. Incomati River etc)			Integrated modelling project "Catchment2Coast" with potential for association with "AfriCat"	P. Monteiro

* This list of suggested sites is not exclusive and is subject to amendment.

2. REGIONAL ASSESSMENT AND SYNTHESIS OF AFRIBASINS

by R.S. Arthurton, H.H. Kremer, Wim Salomons and O. Martins

2.1 Introduction

The **Land Ocean Interactions in the Coastal Zone (LOICZ)** core project of the International Geosphere Biosphere Project (IGBP) is evaluating the physical, biogeochemical and human interactions that influence changes in the state of the coastal environment. The LOICZ key questions that aim to address these issues are:

- How are humans altering the mass balances of water, sediment, nutrient and contaminant fluxes, and what are the consequences?
- How do changes in land use, climate and sea-level alter fluxes and the retention of water and particulate matter in coastal zones, and affect morphodynamics?
- How can we apply knowledge of the processes and impacts of physical, biogeochemical and socio-economic changes to improve integrated coastal management?

Coastal zones worldwide are subject to many pressures, both natural and anthropogenic, which change over time. Management practices in Europe and North America over recent decades have significantly decreased the impacts there of "classical" contaminants such as heavy metals, nutrients and PCBs, but nutrient inputs show only minor reductions. In emerging economies, these latter substances have a high priority. In addition, new classes of industrial and agricultural chemicals have entered the priority lists of international organisations and should become the subjects of coastal impact and monitoring studies. Increasingly coastal areas are subject to a "competition for space" – urban and industrial development pressures, tourism and increased traffic all demand physical space, constraining the size and functioning of coastal ecosystems and creating major challenges for managers and regulators. Past and planned physical changes in river catchments, particularly by damming and diversion, influence the natural flow of water, nutrients, sediments and pollutants to the coast. Numerous studies have addressed these issues and produced large amounts of data, but these data have seldom been subjected to integrated assessment and synthesis. Only recently have the interactions of the physical and biogeochemical environments and human historical evolution been considered. As a step in this process, information and response strategies relating to coastal states, including many in Africa (UNEP 1999; UNEP *et al.* 1997, 1998), have been reviewed under the "Global Programme of Action for the Protection of the Marine Environment from Land-based Activities".

The LOICZ-Basins project is working *inter alia* to develop a global assessment of the importance of changes in river catchments and their impacts on coastal seas by applying a "systems" approach. The river catchment and its associated coastal zone are treated as one system (Figure 1.1). Changes in the coastal zone are affected both by local human activities and by its biophysical properties. Thus, on a global scale, regional coastal zones will show differences in their responses to a similar human activity. The regional systems are subject to outside (long-term) pressures and drivers including climate change and global socio-economic changes. To elucidate these intricate relationships, LOICZ-Basins focuses on the horizontal fluxes of substances within the catchment-to-coastal sea system. This systems approach, integrating the natural and social sciences, addresses issues such as critical concentrations and loads, biological resilience and carrying capacity of the coastal environment. Airborne flux of fine sediment is not considered in this approach.

LOICZ-Basins uses a standardised DPSIR framework, developed by the OECD (1993), for the assessment, analysis and integration of the results of past studies (see Appendix 1). This permits a combination of the results from the natural and social sciences as well as feedback from and to policy/management options (Turner *et al.* 1998; Salomons *et al.* 1999). To generate a global picture, a set of standardised (and thus comparable) regional assessment workshops has been implemented, aiming to scale up information from individual river catchment-to-coastal sea systems to sub-regional and, finally, regional scales. Characteristic types or classes of coastal issues and changes are identified, prioritised and linked to their major natural and anthropogenic drivers on a catchment scale. Numerical or qualitative indices are developed to allow this prioritisation and to permit qualitative or semi-quantitative comparison of the scenarios of land-driven coastal change within and across regions.

LOICZ-Basins therefore deals with the roles of human society on the transport of materials – water, sediments, nutrients, heavy metals and man-made chemicals – within the catchments and the impacts of those roles at the coast and in the coastal sea. In addition it aims to propose feasible management options along with an analysis of the successes and failures of past regulatory measures. Since the changes in fluxes are mostly land- or river catchment-based, the catchment-coastal sea system is treated as one unit – a water continuum. Applying this scale to coastal change phenomena, human activity drivers including agriculture, fisheries, urbanisation, industrialisation, transport and tourism, as well as morphological changes in the catchment (notably damming) have to be taken into account in as far as they affect the fluxes. In particular the following parameters are assessed:

- material flow of water, sediments, nutrients and priority polluting substances (past, present and future trends);
- socio-economic drivers that have changed or will change the material flows;
- indicators for the impact on coastal functioning; and to derive from them
- a "critical load" for the coastal zone and "critical thresholds" for system functioning.

The assessment enables the visualisation/mapping and up-scaling of the issues and scenario simulation on various spatial and temporal scales. It is expected, ultimately, to use the LOICZ typology approach for global up-scaling, which is under continued development in co-operation with IGBP-BAHC (Biospheric Aspects of the Hydrological Cycle core project).

Basins has established links with other global assessment projects including the UNEP-led, GEF-funded Global International Waters Assessment (GIWA), with which it has much of its DPSIR methodology in common. It contributes directly to UNEP's Integrated Coastal Area and River Basin Management initiative (ICARM) as well as UNESCO IOC Integrated Coastal Area Management (ICAM) and Coastal GOOS (Global Ocean Observing System) programmes. LOICZ has agreed to channel the AfriBasins results into the joint ACOPS (Advisory Committee for the Protection of the Sea)-IOC African Process, which already has the political endorsement of at least 11 countries in the region and will feed into the Johannesburg World Summit on Sustainable Development to be held in September 2002.

Outputs from the AfriBasins I workshop (contributor – O. Martins)

During the first LOICZ AfriBasins workshop held in Nairobi 25-28 July 2000, a comprehensive scientific and institutional network was established. This included representatives of the Global Environment Facility (GEF, Biodiversity and Land Degradation), the World Bank (African Water Resources Management Forum Interim Task Force) and UNEP (Division of Environmental Impact Assessment and Early Warning and the Division of Policy Development and Law).

The AfriBasins I workshop was successful in building a regional, multidisciplinary network of scientists, bringing together their experience and knowledge of published work and other relevant existing information, and identifying projects within the region with mutual agendas and/or the potential to be associated with the regional synthesis. The workshop identified the pertinent regional issues, providing a preliminary rank order of current and predicted impacts with analyses of their trends on the basis of the expert judgement of the participants and published scientific information.

AfriBasins I proposed an interim shortlist of potential demonstration sites for the development of case studies addressing some of the prioritised driver-impact issues. It identified the following catchment-coastal systems from five geographical African sub-regions:
North Africa – Alexandria delta (Nile representing a large transboundary system with well investigated drivers of change, especially damming, and a good coverage of biogeochemical and other scientific data)
South East and East Africa – Zambezi and Tana rivers representing systems of different sizes, one (Zambezi) under huge damming pressure and with no comprehensive investigation in place and the other (Tana) currently the subject of planned damming and with an holistic scientific investigation underway.

Also up to two smaller catchments under variable human pressure representing the mainly monsoon-driven East African systems with high seasonality in biogeophysical and hydrological characteristics.
West Africa – the three basins of the Niger, Volta and Senegal rivers (all with potential for up-scaling being transboundary, under strong human impact such as damming and deforestation and subject to various on-going and planned initiatives);
North West Africa – 2 or 3 smaller catchments in Morocco (representing highly influenced river systems in an arid climate with seasonal variance in runoff).

Finalising the regional synthesis: AfriBasins II

Drawing on the work by the network of African scientists in AfriBasins I and attempting to fill the disciplinary and knowledge gaps identified at that workshop, AfriBasins II aimed to finalise the preliminary integrated regional assessment and to provide a link to the first global LOICZ-Basins synthesis. A state-of-the-art regional overview and an identification of "hot spots" to be picked up in a proposal for future regional integrated research were the immediate products expected from the workshop. It was recognised, however, that the information and participant-experience bases for this assessment exercise were, of necessity, restricted and that there would be a need for a comprehensive bibliography and a thorough review process.

The assessment took into consideration the variety of geographical/climatic sub-regions and river catchments of various sizes, many with transboundary issues. It recognised that African regional seas and rivers are most visibly influenced by global change and anthropogenic activity, and that human adaptation to this forcing is itself generating severe impacts on systems functioning. The workshop therefore aimed to provide a range of current and future trend information on loads and critical thresholds, which would feed into the scenario simulation efforts of new research.

The AfriBasins II workshop adjusted the sub-regional divisions that had been proposed in AfriBasins I, now recognising a total of eight sub-regions (see 2.3). Using the standardised proforma tables based on the DPSIR framework (Figure 1.1), two working groups completed the assessment compilations at catchment and sub-regional levels for the western and eastern/north-eastern coasts of Africa respectively. The emphasis throughout was on a close coupling of the physical and biogeochemical sciences with the human dimensions both of the driver-pressure settings in the catchments and of the issues and impacts at the coast. Finally the sub-regional assessments were scaled up to the regional level.

The standardised LOICZ-Basins assessment tables were used to guide a detailed sequence of assessment steps (see Chapter 5). Key questions were posed at each step.

1. Assessing and ranking coastal **Issues/Impacts** (together with their **critical thresholds**) due to human activities within catchments based on documented coastal changes in the region:
- What are the major impacts (coastal issues) identified at the coast or in the coastal sea?
- How close are these impacts to their respective critical thresholds of system functioning?

2. Assessment and ranking major catchment-based **Drivers** and their consequent environmental **Pressures** impacting on the coastal system:
- What are the major driver/pressure settings at catchment level causing coastal change and what are the temporal trends of the changes?
- What are the spatial scales on which specific driver/pressure settings impact on the coastal system?

3. Assessing and ranking the various **Driver/Pressure** settings generating the coastal **Issues/Impacts** and identifying the trends of changes to the **state** of the coastal environment; then up-scaling to sub-regional then regional levels:
- What are the major driver/pressure settings causing observed coastal impacts?
- What are the future trends at sub-regional level; at regional level?

4. Assessment and synthesis of **scientific, policy and/or management responses**:

- What is the current status of the responses taken on scientific, policy or management levels to address the perceived major coastal issues in the region?

5. Assessment and synthesis of **gaps in understanding**, **"hot spots"** and **research needs**:

- What are the major gaps in our understanding of river catchment-coastal sea interactions in the Africa region and which "hot spots" should be addressed with priority in a future integrated scientific work proposal (natural and socio-economic disciplines)?

The issues were evaluated according to the sub-regional division made by the experts for the river systems shown in Figure 2.1. These rivers represent a reasonable coverage of the geographic and/or climatic sub-regions or types of catchment-coastal sea systems identified as being characteristic of the African continent.

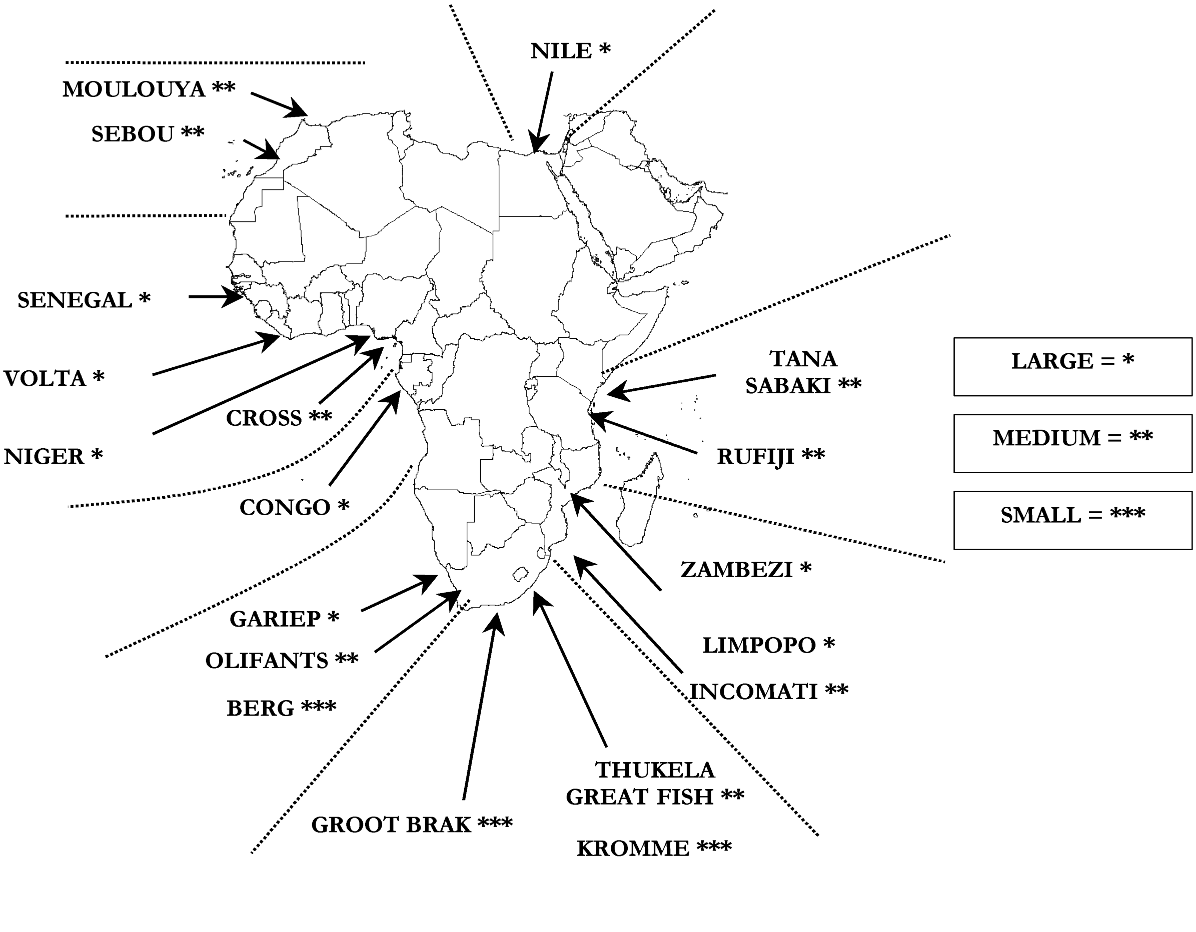


Figure 2.1 Sub-regions (dashed lines) and rivers in three catchment size classes (<10,000; 10,000 – 200,000; >200,000 km²) evaluated for issues, pressures, drivers and land-based activities in AfriBasins II workshop.

2.2 Indicators for coastal change

The availability of reliable information on critical loads and thresholds for catchments within the region is patchy. In the AfriBasins II workshop the identification of indicators for changes in environmental states at the coast was supported as being a realistic aim for the assessment process. Information gaps in respect of thresholds were not considered critical.

While some of the indicators for coastal change that have been cited in the AfriBasins II assessment are policy-related, most belong to the ecosystem approach (see section 2.1 and Table 2.1) and are supported by a wide range of measurable or otherwise observable indicator parameters. Some indicators relate directly to a coastal issue, e.g., the measurable rate of shoreline retreat or advance as an indicator for coastal erosion or sedimentation. Others are less precise, e.g., the assessment of crop yields as an indicator for estuarine salinisation. International conventions on chemical concentration threshholds provide direct indicators for water quality issues (pollution, eutrophication, nutrient depletion). Biological indicators such as algae and seagrass are used as proxy indicators of water quality, but also as direct indicators for the loss of biological function and loss of biodiversity.

The critical loads of water, sediment, nutrients and pollutant fluxes, excesses (or shortfalls) of which may cause significant changes of state and thus possibly major impacts on the coastal system, are generally poorly known for the region. Coastal erosion and sedimentation may be one of the more obvious coastal changes, but its causes may be difficult to attribute (see 2.4). Only if it is certain that the shoreline changes are due to changes in the rate of sediment discharge from rivers will the estimation of a critical threshold for system functioning be meaningful. Similar caution should be applied in assessing the critical loads of nutrients and pollutants discharged from river basins in the vicinity of major coastal urban and industrial centres unless the sources, for example of recognisable pollutants, can be determined. The capacity of the coastal environment for retention, and the potential for dispersal, of nutrients, pollutants and fine sediments are other factors to be considered in the assessment of critical loads and thresholds, though relevant data within the region are generally sparse.

Table 2.1. Summary of environmental indicators of drivers, pressures and state changes applied in the African regional context (based on OECD 1993).

Drivers/pressures	States/state changes	Indicators (examples)	Responses
Damming Diversion Water abstraction	• Coastal erosion • Sedimentation through reduced river flushing • Salinisation • Nutrient depletion in coastal seas • Loss of biodiversity • Increase in aquatic weeds	• Shoreline change • Siltation of channels, harbours • Groundwater salinity increase, reduced crop yields • Fisheries stock changes • Changes in species composition and abundance	• egislation and enforcement measures • CZM strategies • oastal/environ-mental management authorities
Deforestation	• Siltation • Loss of biodiversity	• Changes in distribution of healthy corals and seagrass	• ICZM strategies
Agriculture	• Siltation • Eutrophication • Pollution • Loss of biodiversity	• Excessive algal growth/blooms • Incidence in relation to agreed conventions	• Maximum allowable concentrations (MAC)
Urbanisation Human settlement	• Eutrophication • Human health issues • Loss of biodiversity	• Excessive algal growth/blooms • Incidence of water-related diseases	• Legislation and enforcement measures • MAC
Industrial growth	• Pollution • Loss of biodiversity	• Incidence in relation to agreed conventions	

2.3 Biophysical sub-regions and catchment-size classes (see Figure 2.1)

Building on the results of AfriBasins I, eight sub-regions were identified for assessment within the Africa region, on the basis of their general (catchment and coastal) geomorphological and climatic characteristics. As outlined in Chapter 1, these were:

1. North-west Africa (Morocco) – a relatively arid sub-region with seasonal runoff characteristics and at least in Morocco major human pressure through diversion and damming causing a variety of coastal change issues. (This sub-region includes the coastal stretches of Algeria and Tunisia but no information on systems there was gathered during the AfriBasins process).
2. West Africa (Cameroon, Nigeria to Senegal) – featuring a variety of large rivers subject to major damming resulting in reduced sediment and water fluxes and reduced coastal stability as a growing threat to the lagoon-based cities. In this sub-region there is also a class of ephemerally draining systems with considerable total annual run off such as the Cross and Imo Rivers; about 70 to 85 % of their annual runoff concentrate around the five months, from June to October (FAO, 1997).
3. Congo (Central Angola to Cameroon) – central African sub-region including the very large Congo catchment with extensive rainforest but little information available about its land-based drivers and how they relate to coastal issues.
4. South-west Africa (Cape of Good Hope to southern Angola) – mainly dominated by the upwelling system of the Benguela cold current; cool and temperate in the south, arid in the north with limited river runoff to the coastal sea.
5. Nile – including the wider coastal stretches influenced by the Nile discharge reflecting land-based drivers including the Aswan dam, Cairo urbanisation and industrialisation, and agriculture in the Nile valley and Delta.
6. East Africa (Somalia to Nampula province, northern Mozambique) – featuring small- and medium catchments under monsoonal forcing (seasonal flushing) and subject to damming, and special for the occurrence of extensive fringing and patch coral reefs.
7. Central/southern Mozambique (Zambezi to Maputo Bay) – high seasonality in runoff characteristics (including intermittent cyclonic flooding) and transboundary issues including damming and impacts such as salinisation in the coastal zone; alluvial coast.
8. South-east Africa (Maputo Bay to Cape of Good Hope) – ranging from subtropical in the north to warm temperate on the Eastern Cape coast and characterized by generally small catchments that are subject to various human use patterns with plans in place for intensive damming.

For the purposes of the assessment the river catchments that were selected for analysis were categorised on the basis of their areas: large basins – greater than 200,000 km^2; medium – 200,000-10,000 km^2; and small – less than 10,000 km^2 (see Table 2.2).

Table 2.2. African drainage basins assessed in AfriBasins.

River (basin classes) L = Large M = Medium S = Small	Basin size class	Basin area (10^3 km^2)	Water discharge ($m^3 s^{-1}$)	Sediment load (10^6 t yr^{-1})	Sediment yield (t km^{-2} yr^{-1})	Receiving coastal sea
Nile	L	2870 (3349-Nile Basin Initiative)	10 (2854*)	Negligible (120 pre-damming)	no data (0*)	Mediterranean
Zambezi	L	1500 (1300*)	3361 (3170*)	47.3 (20*)	24.1 (15**)	Indian Ocean
Limpopo	L	412 (410*)	177 (168*)	34.6 (33*)	74.6 (80**)	Indian Ocean
Gariep (formerly Orange)	L	1000 (1100*)	180 (348*)	35 (20*)	35 (18**)	South Atlantic
Congo	L	3700 (3800*)	46000 (46300+-38050*)	67.5 (43*)	11.6 (12**)	Atlantic
Niger	L	2240 (1200*)	6130 (6342*)	40.9	17.8 (18-33** depending on Basin area)	Atlantic
Volta	L	390 (400*)	800 (1268*)	1.509	<0.1	Atlantic
Senegal	L	290 (270*)	10-6736 (675)[1]	1.18-2.86[2] (21*)	(78**)	North Atlantic
Tana	M	132 (42*)	126 (149*)	3	no data	Indian Ocean
Sabaki	M	70	63 (32*)	2	no data	Indian Ocean
Rufiji	M	188 (180*)	900 (983*)	(17*)	(94**)	Indian Ocean
Incomati	M	46	101 (73*)	no data	no data	Indian Ocean
Thukela	M	29.1	146 (95+)	10.5	375	Indian Ocean
Great Fish	M	29.3 (29.9++)	17 (3.2-58++)	high but unknown	no data	Indian Ocean
Olifants	M	46	38	2.7	58.7	South Atlantic
Cross	M	48	1649 (FAO, 1997)	no data	no data	Atlantic
Sebou	M	40	131 (139*)	26	995 (650**)	North Atlantic
Moulouya	M	53.5 (51*)	13 (51*)	12 (6.7*)	240 (224**)	Mediterranean
Groot Brak	S	0.1	0.8	very little	no data	Indian Ocean
Kromme	S	0.94	3.3 (0.1+)	little – all trapped	no data	Indian Ocean
Berg	S	6.42 (7.72++)	22 (16++)	no data	no data	South Atlantic

Where possible figures derived by the AfriBasins team are displayed in comparison to earlier data such as from the GLORI database to give an impression of the partly high variability in curemntly available information for certain systems. Where no data could be provided during the workshop external sources have been used to fill gaps such as FAO and LOICZ information or data have been calculated from such databases.

[1] The values are relative to the Bakel station and the first ones are the minimum and maximum while the number in brackets is the mean module for a 90-year period.

[2] The values are relative respectively to the years 1982-83 and 1981-82.

Data from: Allanson & Read 1995; Berg 1994; CSIR 1985; Department of Water Affairs and Forestry 1996; Haida 2000; Dr D. Hughes, Institute for Water Research, Rhodes University, Grahamstown, South Africa, pers. comm.; Kane 1985; Kitheka 2001; Meybeck & Ragu 1995; Michel & Sall 2000; Morant 1983; Niang 1999; Peters 1978; Reddering & Esterhuysen, 1983; Rooseboom 1992; Snoussi *et al.* 2001; UNEP 1998; * = corresponding figures taken from or ** = calculated from the GLORI database, Milliman et al., 1995; + = Dupra et al. 2001; ++ = Dupra et al. 2002; FAO 1997 – http://www.fao.org/docrep/W4347E/w4347e0w.htm

2.4 Coastal issues, state changes, critical loads and ranking (see Table 2.3 and Chapter 5)

On the basis of referenced information, the working groups identified for each of their respective sub-regions the key environmental and human issues or impacts affecting coastal areas (including the coastal sea) that were considered to have been caused, or influenced, by land-based human activities. The issues include matters of management concern at local, national and regional levels. Generally they involve changes in the state of the coastal environment that impact on its geomorphology and/or its ecosystem, affecting issues such as water quality, biological functioning and human health. The state changes that affect coastal geomorphology relate mainly to the sediment that is discharged from rivers. Examples are where reductions in discharge at river mouths contribute to the impoverishment of sediment on adjoining beaches and the consequent erosion of beach heads (coastal erosion) as in the Nile Delta, or where increases lead to sedimentation (siltation) and coastal progradation as with the case of discharge from the Sabaki River at Malindi in Kenya. While the coastal ecosystem has a natural biological resilience and is able to cope with biogeochemical changes to some extent, certain functions may be damaged or otherwise altered if the changes exceed critical thresholds (see 2.2). An example of this is the growth of toxic algae in an estuary where eutrophication resulting from the discharge of untreated sewage exceeds a critical level.

Distinguishing between natural and human activity drivers as influences on state changes is a particular problem in the assessment of coastal impacts and issues. For example, the possiblity that marine forcing (changes in sea level and/or climate-driven longshore drift) rather than catchment activities might be the cause of some of the cases of erosion and sedimentation that are detailed in the AfriBasins assessment must be borne in mind. Understanding natural processes and their variability over time (e.g., short- and long-term climate change), as they affect both the catchments and the coast, is an important prerequisite for an assessment of the contribution that human activities may make to coastal change. Another problem in the assessment process concerns the weight to be attached to land-based human activity drivers at the coast itself, rather than within identified catchments. The situation is well illustrated by the coastal city of Alexandria with its important issues of pollution, eutrophication and human health attributed to urbanisation and industrialisation separate from any identifiable catchment. For the purposes of the listing of coastal issues, such cases have been included and ranked in the assessment, though generally there is no scope for including them, however acute they may be, in the catchment-by-catchment review of driver/pressure settings assessed in Chapter 5 (see 2.6). An exception has been made, however, in the case of coastal urban nodes in the south-west Africa sub-region.

In ranking the coastal issues and impacts, it has proved difficult to achieve a consistency of standards between, and even within, sub-regions. Local, short-term hot spots may have attracted high rankings – beyond the threshold–yet more spatially widespread and longer-term impacts that have been assigned lower rankings may actually turn out to be the more significant. Even in simple cases, ranking the issues and impacts and the state changes as part of the assessment has, by its nature, been a process of somewhat subjective judgement within the limitations of the mostly sparse data. This may have led to anomalies in the assessment output.

Information regarding both the coastal environmental state and the critical loads and thresholds relating to the various impacts varies greatly in both its quality and availability. The working groups regarded scarcity of data, particularly time-series data, as being a serious impediment to the understanding of the driver-impact linkages throughout the region.

Table 2.3 Major coastal issues/impacts and critical thresholds along the coast of Africa; overview and qualitative ranking of impacts
Impact scale: 10 = maximum; 0 = none.

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Erosion	Morocco: a. Atlantic coast b. Mediterranean coast	No specific threshold are available	a. Exceeded. Estimated erosion between 0.05 and 0.4 $x10^6$t/yr . b. Exceeded. Observed coastal erosion of 0.06 $x10^6$t/yr; 2-5m at Tangiers Bay due to the port extension	a. 7 b. 9	Snoussi *et al.* (1990) Charrouf (1991) Probst & Amiotte-Suchet (1992) Zourarah (1994) Haida (2000)
	a. Volta b. Senegal c. Niger	a. Greater than $1.5x10^6$t/yr b. Greater than $1.5x10^6$t/yr c. Not known	a. Exceeded b. Not exceeded in term of catchment influence c. Exceeded (not sure of cause)	a. 8 b. 5 c. 8	a. Gordon (1998) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996); Kane (1997) c. NEST (1989)
	a.Rosetta promontory b.Burullus Lake area c.Damietta promontory	a. Current erosion rate 53-102 m/yr b.Erosion rate: 5.5 m/yr c.Erosion rate: 10.4 m/yr	a. Aswan Dam (1968) prevented sediment discharge (160 Mt/yr) into Mediterranean.	a-c. 9	a. Hydraulic Resource Analysis (1992); Frihy & Lotfy (1994); Frihy *et al.* (1994) b.Frihy & Dowidar (1993) c.Frihy & Komar (1993)
			b.		

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Erosion continued	a. Tana delta b. North Kenya coast (Shanzu, Kanamai), South Kenya coast (Diani, Likoni); contributing rivers unknown c. Bagamoyo and Dar es Salaam (Ruvu river) d.Rufiji e. Mtwara-Lindi stretch (Mbemkuru and Ruvuma rivers) f. Kilwa (Rufiji river) g. Jambiani, Paje, Maruhubi, Nungwi areas in Zanzibar	a. Not known b. Not known c-g. Not known	a. Not known b. Critical load already passed c. Critical load already passed for Bagamoyo and Dar es Salaam (4m retreat per year) d-f. Erosion considered to be occurring, rate unknown g. Critical load passed for Jambiani, retreat estimate unknown	a. 8 a. 8	a. Raal & Barwell (1995); Knocker (1998) b. Okemwa *et al.* (1994) c-g. Mushala (1978); Ross & Saint-Ange (1986); Fay (1987, 1992), Griffiths (1987); Lwiza & Bigendako (1988); Arthurton (1992); Shaghude *et al.* (1994); Arthurton *et al.* (1999); TCMP (2000, 2001); Ngusaru *et al.* (2001); UNEP (2001)
	a. Zambezi b. Limpopo c. Incomati estuary	a. Unknown c. Unknown	a. Unknown c. Erosion becomes a continuous process	a. 8 c. 8	a. Gove (1993) c. MICOA (1998)
	a. Thukela b. Great Fish c. Kromme d. Groot Brak	a. 60% existing flow b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 3 b. 3 c. 2 d. 2	Thukela: Begg (1978)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Sedimentation	Atlantic coast and Mediterranean coasts of Morocco	Not known	Marine sedimentation exceeds fluvial sedimentation in many sites of both the Atlantic and Med. coasts, due to the impoundment of water flows and the reinforcement of the marine influence. The littoral drift is estimated between 0.25 and 8 x10^6 t/yr. All ports and estuaries are silted. 0.7x$10^6$$m^3$ of sediments are deposited annually in the Sebou estuary. This affects navigation channels necessitating dredging. The inlets of the lagoons are periodically closed.	9	Charrouf (1991) Snoussi *et al.* (2001)
	a. Volta b. Senegal c. Niger	a. 2 km of shoreline development over 10 years b. Marine sedimentation exceeding fluvial sedimentation c. Not known	a. Exceeded b. Exceeded c. Exceeded	a. 7 b. 9 c. 6	a. Gordon (1998) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996) c. NEST (1989)
	a. Gariep b. Olifants c. Berg	a. Not known b. Not known c. Not known	a. Not exceeded, but could be near threshold b. Not exceeded c. Not exceeded	a. 4 b. 3 c. 3	a. DWAF (1989); DWAF (1993) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
	All Mediterranean coastal lagoons	Area reduced from 960,000 to 260,000 hectares in last 40 years	Uncontrolled land reclamation; urbanisation	8	Hanafy(1998)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Sedimentation Continued	a. Tana delta and Ungwana Bay b. Sabaki mouth and Malindi Bay c. Port Reitz/Mwache creek d. Rufiji e. Ruvuma	a.b. Unknown but could be about 5% of annual load. Silting of Malindi Bay. Smothering of coral in Malindi Marine Park. d. Smothering of seagrass beds and coral near Rufiji delta and the south of Mafia Island, siltation as far as Mkuranga.	a. Critical load already passed. Tana sediment load 1-8 mt/yr b. Sabaki sediment discharge 2 mt/yr d. Critical load passed e. Unknown	8	a-b. Gibb (1959); ILACO (1971); Dunne (1975); Dunne & Ongwenyi (1976), Edwards (1979); UNEP (1998); Otieno & Maingi (2000). c. Kitheka (2000) d. Francis (1992); Fisher *et al.* (1994); Ngusaru *et al.* (2001)
	a.Zambezi b.Limpopo c.Incomati	a. unknown	a. unknown	a.8 c.9	a. Balek (1972) c. MICOA (1998)
	a. Thukela b. Great Fish c. Kromme d. Groot Brak	a. 60% existing flow b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 4 b. 2 c. 2 d. 3	Great Fish: Watling & Watling (1983); Allanson & Read (1987); Whitfield (1994); Whitfield *et al.* (1994); Allanson & Read (1995); Ter Morshuizen *et al.* (1996); Grange *et al.* (2000)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Eutrophication	Atlantic & Med. coasts of Morocco	Actual limit CNP ratio not known Excessive algal growth	Occurrence of low oxygen and high values of nitrogen in estuaries and lagoons. Increasing of frequency of algal blooms	8	Lefebvre *et al.* (1996); Benasser (1997)
	a. Volta b. Senegal (potential issue) c. Niger	a-c. When CNP ratio becomes unbalanced, actual limit not known	a. Exceeded due to presence of algal blooms (offshore and in coastal lagoon) b. Not exceeded c. Exceeded	a. 7 b. 4 c. 7	a. Entz (1969) b. UNEP (1999) c. NEST (1989)
	a. Saldanha Bay	a. Occurrence of excessive algal growth (e.g., *Aureococcus* sp and *Ulva*)	a. Occasionally passes critical threshold in the mid-late summer, particularly in more stratified and depositional areas of the bay (more than would have occurred naturally)		a. Monteiro & Largier (1999); Monteiro *et al.* (1999)
	Abu Qir Bay, adjacent to Nile delta	High nutrient loads, especially P through agricultural drainage and sewage NH_4 – 6-14.2 μg/l NO_3 – 5.7-19 μg/l PO_4 – 1-4 μg/l O_2 - <4 mg/l Chl.a : 15-48 μg/l	Redfield ratio is broken C : N : P 82 : 5.5 : 1	6	Abdel Aziz & Dorgham (1999); Abdel Aziz *et al.* (2001); El Rayis *et al.* (1994)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Eutrophication Continued	Alexandria City coast	Nearshore waters receive 200x$10^3$$m^3$ of untreated domestic sewage from two outfalls. Around these sites nutrients are normally found in high concentration: NH_4 – 14.5-38.7 μg/l NO_3 – 5.7-19 μg/l PO_4 – 1-6 μg/l O_2 - <4 mg/l Chl.a : 34-107 μg/l	Redfield ratio is broken C : N : P 218: 4 : 1	5	Zaghloul & Halim (1992); Dorgham *et al.* (2001)
	a. Tana b. Sabaki	a.b. DO level > 5mg/l and TSSC >0.05 g/l	C:N:P ratio not known	4	a. Kitheka (2000)
	a. Zambezi b. Limpopo c. Incomati d. Xinavane, over 80 km of estuary	a-c. unknown d.Anoxia or low Oxygen in estuary	a-c. unknown d. Increased nutrient	a. 2 d.10	a. Mordosova (1980) b. Mordosova *et al.* (1980); Munga (1987); Caralap *et al.* (1993); Masundire & Matiza (1995)
	a. Thukela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 3 b. 2 c. 2 d. 4	Kromme: Watling & Watling (1982b); Emmerson & Erasmus (1987); Sowman & Fuggle (1989); Adams *et al.* (1992); Adams & Talbot (1992); Schumann & de Meillon (1993); Jerling & Wooldridge (1994); Heymans & Baird (1995); Baird & Heymans (1996); Quinn *et al.* (1998); Bate & Adams (2000); Scharler & Baird (2000); Snow *et al.* (2000); Strydom & Whitfield (2000); Wooldridge & Callahan (2000)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution	Morocco a. Med. coast b. Atlantic coast	WMO norms and standards. Baseline concentrations of unpolluted soils of the basin	a. Exceeded, loss of biodiversity. Zn, Cd, Hg , BOD, DOC and pesticides are monitored in the the framework of MedPol Programme. Occurence of red tides twice a year b. Increasing backround level of heavy metals by a factor of 2 in most areas. High values in biota mainly bivalves	a. 8 b. 9	MAP Technical Reports Series Snoussi (1992) CNE (1995) Cheggour (1999)
	a. Volta (pesticide) b. Senegal (pesticide) c. Niger (oil, heavy metals) d. Cross (oil, heavy metals)	a-d. Generic critical thresholds can probably be derived from literature, but currently site specific values are not available	a. Exceeded, loss of biodiversity b. Not known c. Exceeded (oil pollution) d. Exceeded (oil pollution)	a. 6 b. – c. 8 d. 9	a. Czernn-Chudenitz (1971); Amoah (1999) b. - c. NEST (1989); CRP (1999) d. CRP (1999)
	Congo	Not known	?	3	UNEP (1999); Morant (2001); Morant pers. comm.

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution Continued	a. Gariep (pesticides) b. Olifants (pesticides) c. Berg (pesticides) d. Saldanha Bay (oil, heavy metals) e. Table Bay (oil, heavy metals) f. False Bay (oil, heavy metals)	a-c. Generic critical thresholds can be derived from literature, but site-specific values are not available d-f. For harbours, critical thresholds have been recommended for trace metals (under the London Convention, 1973).	a. Not exceeded b. Not exceeded c. Not exceeded d-f. Localised areas in harbours are close to or exceeding critical limits	a. 2 b. 2 c. 2 d. 4 e. 4	a. DWAF (1993) b. Taljaard (1997) c. DWAF (1994) d. Monteiro & Largier (1999); Monteiro *et al.* (1999) e. Quick & Roberts (1993); Monteiro (1997) f. Taljaard *et al.* (2000)
	Mex Bay (River Nile)	Receives 2 bm^3/yr mixed wastewater loaded with $220x10^3$ t/yr BOD; 75x10 t/yr COD; $2x10^3$ t/yr TN; $2.6x10^3$ t/yr TP & $287x10^3$/yr TSS. Standing stocks: 840 t/yr TN; 30 t/yr TP & 3000 t/yr TSM. The Bay environment also receives $75x10^3$ t/yr toxic metals (Hg, Cd, Cr, Cu, Zn & Ni) and 1300 t/yr of Oil.	Hot spot in the Mediterranean; alteration in biodiversity; eutrophication; high levels of toxic heavy metals and PAH are frequently detected in marine fauna and flora; negative impact on fisheries and fish speciation.	9	UNEP (1990); Younes *et al.* (1997); UNEP/WHO (1999)
	Alexandria City coast	Receives 145 Mm^3 /yr domestic wastes loaded with $1.5x10^3$ TN; $2.3x10^3$ t/yr TP, $8.8x10^3$ t/yr TTS, 540 t/yr oil wastes from refineries	Hot spot in the Mediterranean. Health hazards from near shore untreated discharge of sewage. Eutrophication and red tide. Negative impact on fisheries and on submerged archaeological heritage.	5	Atta(1985); UNEP(1990); Awad (1995); UNEP/WHO (1999)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution Continued	Abu Qir Bay (River Nile)	Receives 410 Mm^3/yr mixed wastewater With $90x10^3$ t/yr BOD; $575x10^3$ t/yr COD; $5x10^3$ t/yr TN; $8.5x10^3$ t/yr TP and $120x10^3$ t/yr TSS.	Hot spot in the Mediterranean. The bay's environment suffers from high load of industrial wastes and untreated sewage discharge especially black liquor and fertilizer industry wastes	9	El Deeb (1977); UNEP(1990); UNEP/WHO (1999); Younes *et al.* (1997); Awad & Yousef (2001)
	Edku Lake (River Nile)	Agriculture drains receive about $1bm^3/yr$ drain water. Discharge 400 Mm^3/yr of brackish water into Abu Qir Bay loaded with 12 t/yr NO_2, 8 t/yr NO_3 and 9 t/yr PO_4. ð = 20-60 d, p-r = 3.2 $mmol/m^2/d$ in summer and 1.3 $mmol/m^2/d$ in winter; nfix-denit=1.6 $mmol/m^2/d$ in summer and 22.7 $mmol/m^2/d$ in winter	Nitrogen fixing system frequently its discharge water quality cause eutrophication in the Abu Qir Bay receiving environment	5	Saad (1997); Awad & Hassan (1998); Awad & Yousef (2001)
	Burullus Lake (River Nile)	Discharge into Mediterranean $2.2bm^3/yr$ brackish water loaded with insignificant N & P; (0.03 t/yr NO_2; 0.2 t/yr NO_3 and 0.01 t/yr PO_4	Clean coastal lagoon considered as natural reserve	0	Saad (1997); Awad & Hassan (1998)
	Manzalla Lake (River Nile)	Receives 1.7 bm^3/yr of partially or untreated wastes, discharges 7 bm^3/yr into the Mediterranean loaded with 40 t/yr NO_2; 156 t/yr NO_3 and 71 t/yr PO_4	Hot spot in the Mediterranean	9	EEAA (1992); Awad & Hassan (1998)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution Continued	Damietta Nile Estuary	Stopped discharging freshwater into the Mediterranean following the construction of the El Salam Canal transporting Nile water to Sinai (3.3 bm^3/yr) for irrigation		2	
	Bardawil Lake	Sensitive area, hypersaline lagoon, no discharge and free of pollution	Overfishing (fish catch decreased in 1992 by 40% relative to that of 1970). Biodiversity under threat following the arrival of Nile waters through the El Salam Canal and agriculture activity around the lake with increasing settlement. Impacts on groundwater quality and coastal erosion are predicted.	0	UNEP/WHO (1999)
	a. Mtwapa creek b. Makupa creek c. Kilindini channel d. Rufiji and Ruvuma			5-8	a.-c. Rees *et al.* (1996); Kitheka (2000). d. TCMP (2000, 2001); Ngusaru *et al.* (2001)
	a. Zambezi b. Limpopo c. Incomati d. Maputo Bay	a,b. unknown	a,b. unknown	d.8	d. Hoguane (2000)
	a. Thukela b. Kariega c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 4 b. 2 c. 2 d. 3	Groot Brak: Day (1981); Watling & Watling (1982a); Morant (1983); Slinger & Breen (1995); Slinger *et al.* (1994); Coetzee *et al.* (1997)
Aquatic weeds	Med. Coast	Presence (*Caulerpa*)	Exceeded	7	MAP Technical Reports Series

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Aquatic weeds Continued	a. Volta b. Senegal c. Niger (nypa) d. Cross (nypa)	a. Presence b. Presence c. Presence d. Presence	a. Exceeded b. Exceeded c. Exceeded d. Exceeded	a. 7 b. 9 c. 7 d. 9	a. De Graft-Johnson (1999) b. Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); Matera & Malaisse (1999) c. CRP (1999) d. AKS (1989)
	a. Table Bay b. False Bay	a. Occurrence of nuisance reed beds b. Occurrence of nuisance reed beds	a. Exceeded in some estuaries due to nuisance reed growth b. Exceeded in some estuaries due to nuisance reed growth		a. Quick & Roberts (1993) b. Taljaard *et al.* (2000)
Biodiveristy loss (Loss of biological function)	Morocco a. Med. Coast b. Atlantic	Change in species composition and abundance	a. Exceeded. Loss of marine turtles (5000/yr), monk seals, and red coral reefs due to overexploitation and pollution. Complete loss of *Posidonia*. b. Declining fishery stocks, lobsters (Dakhla Bay), octopus (sp) and carpet-shells	a. 7 b.9	MAP Technical Reports Series Menioui (2001)
	a. Volta b. Senegal c. Niger (mangroves loss) d. Gambia (mangroves loss)	a-c. Change in species composition and abundance	a. Exceeded b. Exceeded c. Exceeded	a. 7 b. 8 c. 7	a. Gordon (1999) b. Bousso (1992); Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); c. Ibeanu (2000)
	Congo	Not known	?	7	UNEP (1999); Morant (2001); Morant pers. comm.

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Biodiveristy loss (Loss of biological function)	a. Gariep b. Olifants c. Berg d. Saldanha Bay e. Table Bay f. False Bay	a. Not known b. Not known c. Not known d. Not known e. Not known f. Not known	a. Probably exceeded or near through large salt marsh areas being cut off from river by the coastal road b. Not exceeded c. Not exceeded d. Exceeded in localized areas, e.g., harbour area e. Exceeded in localized areas, e.g., estuaries f. Exceeded in localized areas, e.g., estuaries	a. 6 b. 3 c. 3 d. 6 e. 6 f. 6	a. DWAF (1993) b. Huizinga & Van Niekerk (1997); Taljaard (1997) c. DWAF (1994) d. Monteiro & Largier (1999); Monteiro *et al.* (1999) e. Quick & Roberts (1993) f. Taljaard *et al.* (2000)
	a. Ungwana Bay-Tana b. Funzi Bay c. Bamburi-Nyali lagoon d. Diani-Gazi lagoon e. Rufiji-Kilwa-Mafia complex f. Mnazi Bay - Ruvuma estuary complex.	a.-d. Fish stock and biological productivity indicators b.-d. Contributing rivers not known	a.d. Fish landing declining over the years – 10,000 t/yr e-f. Biodiversity loss in mangroves, coastal forests, coral habitats	8	Kenya Fisheries Department records; KMFRI database; Muthiga & McClanahan (1987); Wells & Sheppard (1988); McClanahan & Mutere (1994); McClanahan & Obura (1995); Watson (1996); Glaesel (1997); Mwatha (1998); Malleret-King (2000); Ochiewo (2001). e. IUCN (1996); Ngusaru *et al.* (2001)
	a. Zambezi delta b. Sofala Bank c. Limpopo d. Incomati	a,b. Ecosystem collapse – sardine fishery, *Posidonia* disappeared, primary productivity severely reduced - prawn fisheries	a,b. Exceeded	a,b.10	a,b. Da Silva (1986); Gammelsrod (1992, 1996); Hotton & Munguambe (1998); Guale (2000)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Biodiveristy loss (Loss of biological function)	a. Thukela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Modified by freshwater input c. Functional but marine-dominated d. Unknown	a. 4 b. 3 c. 5 d. 4	
Salinisation	Coastal plains of Moulouya, Sebou, and Oualidia	Not known. Excess of salts in wells (water for drinking and irrigation)	Exceeded in most of the irrigated coastal plains, due to over extraction of groundwater. Over use of fertilizers, and droughts.	9	Moussaoui (1994) El Mandour (1998)
	a. Senegal b. Niger c. Cross	a. Not known, because the system is complex b. Not known c. Not known	a. Not exceeded b. Exceeded c. Exceeded	a. 5 b. 7 c. 7	a. BDPA-SCETAGRI *et al.* (1995); Diouf (1998); Pages *et al.*, 1987; Debenay *et al.* (1994) c. Ibeanu (2000)
	a. Gariep b. Olifants c. Berg	• a. Not known • b. Not known • c. Not known	• a. Not exceeded • b. Not exceeded • c. Not exceeded	a. 3 b. 3	a. DWAF (1989) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
	Nile				EEAA (1992)
	a. Rufiji delta				a. Tafe (1990); Ngusaru *et al.* (2001)
	a. Zambezi b. Limpopo c. Incomati to 80km from mouth	a. unknown b. unknown	a. unknown b. unknown	c.10	c. Matola, J. (1999)

Table 2.3 continued

Coastal impact/issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Human health issues	Morocco	Presence of disease	Close to threshold in some areas	6	
	a. Volta (invasion of snails/water related diseases) b. Senegal (Invasion of snails/water related diseases) c. Niger (water related diseases) d. Cross (water-related diseases)	a. Presence of disease b. Presence of disease c. Presence of disease d. Presence of disease	a. Exceeded b. Exceeded c. Exceeded d. Exceeded	a. 8 b. 8 c. 7 d. 7	a. Derban (1999) b. Handschumacher *et al.* (1992); Talla (1993); Niang (1999) c. NEST (1989) d. Ibeanu (2000)
	a. False Bay b. Table Bay	a-b. *E. coli* counts not to exceed 100 counts/100 ml for 80% of the time and 2000 counts/100 ml for 95% of the time	a-b. Thresholds exceeded in localized areas (within 500 m of river mouths and storm water discharges).	a. 4 b. 4	a. CMC (1999) b. Taljaard *et al.* (2000)
	a. Tana b. Sabaki c. Umba estuary/ Vanga d. Rufiji-Kilwa-Mafia complex e. Ruvuma estuary	Not known but there are: a. Increasing conflicts resulting in loss of human lives a & c. Increased occurrence of water-borne diseases a & c. Reduced productivity due to ill health.		8	a-c. Ochiewo (2001) d-e. Ngusaru *et al.* (2001)
	a. Thukela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 2 b. 2 c. 2 d. 3	

2.5 Driver-Pressure-State relationships

Socio-economic **drivers** within the catchments cause environmental **pressures**, which affect, with different time delays, the inputs and fluxes of substances to the river systems and, after transformation in those systems – in their estuaries (or deltas) and associated coastal lagoons – the discharge of those substances to the coastal sea. The flow of substances is modified both temporally and spatially by the geomorphological and biogeochemical properties of the basins, the estuaries and their contiguous shores. The **state** of the three different types of aquatic ecosystem (river, estuary and coastal sea) represents the condition of significant components of the system that may be affected by these pressures. Changes to this state lead to **impacts**, which may affect both environmental and socio-economic processes at the coast and in the coastal sea. Because of the wide diversity of the African drainage basins, an attempt to present an overview picture of driver-pressure-state relationships beyond the sub-regional scale (see Chapter 5) is considered inappropriate.

The working groups considered the drivers at the sub-regional scale and ranked them numerically according to their respective state changes and consequent impacts on the coastal system. The numbers ranged from 0 (indicating no change) to 3 (indicating a major change). The rankings were applied variously to large, medium and small basins (see 2.3) as appropriate to the specific sub-regions. In the cases of the Nile and the Congo the rankings applied to only one large basin each. The working groups also assessed the time-scales over which changes in the state of the coastal environment were taking place. In some cases the changes were a direct or immediate result of catchment pressures, e.g., impoundment of water and sediment by damming; in others they were gradual or progressive, e.g., continuing deterioration in water quality through the increased discharge of sewage due to urbanisation. The workshop acknowledged the difficulties involved in achieving consistency in the state change ranking process both between the sub-regions and within sub-regions, for basins of different size classes.

2.6 Assessment of land-based drivers (see Table 2.4 and Chapter 5)

Supported by referenced information, the working groups compiled and assessed available information for each of the selected catchments regarding the relationships between the drivers (both natural and socio-economic) in the catchments and the perceived resulting environmental pressures and consequent state changes and their impacts at the coast. The groups assessed the importance of specific drivers in respect of the various impacts and issues, using numerical rankings for the present situation and indicating the trends of future change.

The difficulty in making the correct attributions of drivers to impacts has been a matter of concern throughout the assessment. In cases of pollution, eutrophication and human health there may be few doubts about the identity of the causative driver(s). Specific recognisable pollutants, for example, may be traceable to individual point sources. With erosion and sedimentation, however, the driving forces may be complex and comprise several different contributors (including natural forces) that may be positive or negative in their individual effects on material flux. For example, a river system may have a reduced sediment input as a consequence of damming, while the same system (below the dam) may receive an increased supply due to deforestation or changes in agricultural practice. To make a meaningful assessment of the respective contributions made to, say, the coastal issue of sedimentation by e.g., agriculture, deforestation or damming in the catchment may simply not be feasible on the basis of the data presently available. Thus the impact rankings that have been made should be treated with caution. To some extent such anomalies have been moderated as part of the up-scaling procedure from catchment to sub-regional scales but, where data on the spatial and temporal scales of impact or state change have been unavailable, it is recognised that some rankings, even at sub-regional scale, are tentative.

2.6.1 Catchment scale

(The contributing authors for this section are also the authors of the corresponding assessment tables in Chapter 5.)

The various sub-regions show wide variation not only in the biophysical nature of their catchments but also in the availability and quality of existing data relating to their material fluxes. As far as possible the catchments that chave been chosen for assessment are considered to be representative of the catchments in their respective sub-regions. The Nile sub-region comprises only one catchment. All of Africa's 'big four' river basins, the Niger, Congo, Nile and Zambezi have been included in the assessment, as have the important transboundary basins of the Senegal, Volta, Cross and Gariep rivers on the west coast and the Limpopo and Incomati on the east. Representative medium and small basins have also been assessed. These comprise the basins of the Sebou and Moulouya rivers in Morocco, the Olifants and Berg (west of the Cape of Good Hope) in South Africa, the Tana and Sabaki rivers in Kenya, the Rufiji in Tanzania, and the Thukela, Great Fish, Kromme and Groot Brak in South Africa east of the Cape.

1. North West Africa (contributor – M. Snoussi)
North-west Africa is characterised by young mountains and numerous medium and small drainage basins with strong slopes, while the alluvial plains are few and of limited extent. River runoff and precipitation are irregular and may be high. Poorly vegetated steep slopes are prone to surficial runoff, resulting in soil erosion and high levels of fluvial suspended sediment transport – probably among the highest in Africa.

The Sebou and Moulouya catchments (located in Morocco) are representative of the medium drainage basins that characterise the semi-arid Maghreb area. They have generally been supported by good quality recent data. A wide range of impacts and issues has been reported. Many large dams have been built over recent decades. The resulting sediment entrapment has not only reduced the reservoir capacity, but has also become the principal cause of coastal erosion. Reduced stream flows due to damming are also regarded as favouring the accumulation of marine sediments.

The main sources of coastal eutrophication and pollution are untreated domestic and industrial wastewater and fertilizers. Most of the urban sewage is directly discharged without treatment. Human health issues also arise from the discharge of untreated sewage (related to urbanisation), while loss of biodiversity (or biological functioning) is seen as a complex interplay of all the principal drivers. Increasing salinisation is recognised as a serious issue, caused variously by urbanisation and agriculture (over-abstraction of groundwater) and the natural drivers of climate change and sea-level rise.

2. West Africa (contributors – A. Kane, I. Niang Diop, C. Gordon, G. Umoh)
The assessments of these catchments, including the large basins of the Senegal, Volta and Niger (which have significant transboundary implications) and the medium-sized Cross River basin, have generally been supported by good quality, up-to-date data. A wide range of impacts and issues has been reported. Coastal erosion is a problem associated with all catchments, with critical thresholds exceeded in respect of the Volta and Niger. Damming, deforestation and agriculture are all cited as contibutors, with damming the prime cause in the Volta. Coastal sedimentation is another common issue, especially at the mouth of the Senegal River though in this case not obviously directly due to catchment discharge.

Algal blooms are a manifestation of eutrophication particularly in the Volta and Niger, with urbanisation (or human settlement) and, to a lesser extent, agriculture seen as the principal drivers. Oil-related pollution is an important issue in the Cross River basin, while aquatic weeds such as Nypa palm are reported from all catchments and attributed to damming (Senegal) and a range of other drivers including transport. Critical thresholds for the loss of biological functioning due to a complex of drivers have been exceeded in the Volta and Niger and especially in the Senegal. Human health issues including the incidence of water-related diseases that are attributed to urbanisation have been reported in all catchments, with critical threholds being exceeded in the Volta and Senegal. Salinisation is seen as a problem in the Niger and Cross, where the drivers are unclear, and the Senegal, where climate change (drought) is regarded as the cause.

3. Congo (contributor – P. Morant through S. Taljaard)
The Congo is the second largest river in the world on the basis of annual flow. The system extends over a distance of 4,700 km between Lake Tanganyika and its mouth on the Atlantic Ocean. The dominant characteristic of the river is the remarkable regularity of its regime. The lower reaches of the basin, i.e. below Kinshasa and Brazaville (some 300 km upstream of the mouth) are free of major urban and industrial developments. Two harbours in the lower reaches probably produce some oil-related pollution. Near the coast human activities include fishing, gathering medicinal plants and subsistence cropping. The loss of habitat and biodiversity there as a consequence of mangrove felling for fuel wood is regarded as a

major issue. Little quantitative data, however, is available about land-based drivers and how they relate to coastal issues.

4. South West Africa (contributor – S. Taljaard)
The major perennial river basins in this sub-region that may influence the coastal zone include the Kunene (on the borders of Namibia and Angola – not assessed), the Gariep (formerly Orange, a large basin on the borders of Namibia and South Africa), and the Olifants (medium) and Berg (small) basins (both in South Africa). Urban nodes along this stretch of coast, which also have a significant influence on the coastal zone, include Walvis Bay (Namibia) (no expertise available at workshop), Saldanha Bay (West Coast, South Africa) and Table Bay and False Bay (both Cape Town, South Africa).

Quantitative data on coastal impacts of the Kunene and Gariep basins are very limited. Although some data are available for the Olifants basin, these are limited to impacts on the estuarine region mouth. Data on the coastal impacts of the Berg River basin have up to now also been limited to the estuarine region inside the mouth, but currently studies are underway to extend investigations into the larger St Helena Bay area.

The Gariep estuary is recognised as one of southern Africa's most important coastal wetlands. Its mouth is of delta type, the mouth dynamics being affected by upstream impoundments and associated water use practices. During prolonged low-flow periods, salinisation in the lower reaches, particularly of the groundwater resources, has become a concern.

Human activities in the Olifants catchment appear to have limited impact on its estuary and coastal zone, although damming and agriculture have led to a reduction of freshwater inflow. Flow in the Berg River is very seasonal, with low flows in the dry summer period and higher flows during the wet winter season. The high concentration of dissolved inorganic nitrogen in the winter runoff is attributed largely to fertilizer entering the river through the agricultural runoff.

Impacts of human activities around the urban and industrial nodes include the progressive deterioration of water quality. Eutrophication attributed to industrial development around Saldanha Bay is of considerable concern. Of the urban node embayments, only False Bay receives significant basin drainage, with 11 small catchments discharging to the bay.

5. Nile (contributor – H. Awad)
The damming of this transboundary river system has led to profound changes in fluxes through the Nile delta and in the associated coastal sea (the Mediterranean). This is exacerbated by a rapid growth of urbanisation and industrialisation around Cairo and changes in agricultural practice in the Nile River valley and its delta region. All of these socio-economic drivers, together possibly with the natural driver of climate change, have produced significant impacts at the coast and in the coastal seas around the Nile delta. Notable among these has been the acute coastal erosion around the mouths of the Rosetta and Damietta distributaries of the delta. This is largely attributed to the almost complete cessation since the 1960s of coarse sediment flux below the Aswan Dam. Damming is also seen as being responsible for the increasing salinisation of groundwater in the delta area. Other important coastal issues include eutrophication and pollution of the coastal waters due to the discharge of urban and industrial waste water (Mex Bay and Abu Qir Bay, Mediterranean pollution hot spots) and the loss of habitat resulting from the landfilling of coastal lagoons. Attribution of coastal pollution to fluvial discharge is complicated by the significant inputs from the extensive urban-industrial area of Alexandria at the western limit of the delta (also a Mediterranean pollution hot spot). The assessment is supported by good quality data, including information relating to critical thresholds.

6. East Africa (contributors – J. Kitheka, J. Ochiewo and A. Ngusaru)
The assessed catchments of this sub-region are medium basins, all subject to seasonal flushing, the principal rainfall occurring at the transitions between the north-east and sourth-east monsoons in April and October. All of them discharge on a coast that is characterised by fringing or patch coral reefs with an associated rich biodiversity. The Rufiji discharges through a delta dominated by mangrove forest into coastal waters that include the largely pristine Mafia Marine Park. Coastal erosion and the discharge of sediment are two of the important issues on this coast. Both the Sabaki and the Tana rivers intermittently discharge sand and

fines, the sand being transferred to beaches thence in part to dune systems that characterise the coast of northern Kenya. Fine sediment, carried in suspension as plumes through the coastal waters, may settle and smother growing coral. Beach-head erosion, mainly of earlier-formed beach deposits, is widely reported, but its attribution solely to a reduction in sediment discharge from the catchments is controversial.

The contributions that damming, deforestation and changes in agricultural practice make to increased or decreased sediment input to these systems have been the subject of several studies in the Tana and Sabaki. Most of these suggest that all of these drivers are increasingly contributing to the problems of coastal erosion and sedimentation. The Tana is already dammed and additional dams are proposed there, as they are for the Rufiji. Pollution is recognised as being a significant issue in the Tana and Sabaki basins, with agriculture, industry and urbanisation all making contributions as drivers. In the Rufiji pesticides used in rice cultivation and the impacts of prawn farming are matters of concern, as are the impacts of population growth and the clearing of mangroves for agriculture. However, inputs of pollutants from industrial development around Nairobi in the Sabaki (Galana/Athi) catchment do not appear to cause serious problems at the coast. The pollutants and nutrients (untreated or partially treated sewage) delivered to coastal creeks from the urban-industrial centres of Mombasa and Dar es Salaam may be more significant, though these sites lie outside the scope of the LOICZ-Basins assessment.

7. Central/southern Mozambique (contributors – F. Tauacale, L. Mhlanga)
The assessed catchments of this sub-region, the Zambezi, Limpopo and Incomati, are transboundary in nature, the Zambezi catchment spanning a total of 8 countries. The rivers discharge on a predominantly alluvial coast formed mainly of older beach deposits and barrier bars and spits with associated creek systems, mangrove swamps and sand dunes. Unlike other parts of the eastern coast of Africa, there is an appreciable continental shelf. Most of the coastal issues and impacts are ascribed to damming and agricultural drivers, with the reduction in stream flow recognised as a significant to acute and increasing problem. The middle course of the Zambezi River has been interrupted by two artificial impoundments, Lake Kariba and Lake Cahora Bassa, which cover 5,364 km^2 and 2,739 km^2 respectively.

Coastal erosion reported from the Zambezi delta and the Incomati River is attributed solely to damming and the consequent reduction of sediment discharge. Loss of biological productivity, particularly in the Zambezi system, is seen partly as a consequence of water abstraction for irrigation. The increasing salinisation of agricultural land flanking the Incomati estuary and the nutrient depletion in the coastal seas off the mouths of the Zambezi and Incomati are regarded as impacts of the damming in the respective catchments.

8. South East Africa (contributor – A. T. Forbes)
The catchments assessed in this region comprise one medium basin – the Thukela, discharging on to the sediment based, biologically significant Thukela Bank on the east coast – and three small basins, the Great Fish on the south-east coast and the Kromme and Groot Brak on the south coast. The coast adjoining all these systems, in keeping with the general south-east African condition, is dominated by marine processes being open and subject to strong wave action and longshore drift. Catchment-derived impacts, primarily arising from impoundments, have tended to be recognized primarily in relation to estuarine habitats. The Thukela does, however, deviate from this generalisation.

The Thukela is the largest east coast system and has already been used a source of water via inter-basin transfer for industrial purposes in the Johannesburg area and irrigation along the Vaal River, a tributary of the Gariep. The estuary is still freshwater dominated but it is anticipated that further reduction in freshwater flow would, *inter alia*, extend periods of mouth closure, reduce sediment supply to beaches north of the river and reduce nutrient input to the already oligotrophic inshore marine environment.

The Great Fish has the second largest catchment of the four systems included here but much of it lies in relatively arid areas. Its flow has now been enhanced and stabilised by the inter-basin transfer of water from the Gariep system to the north via pipelines and canals, as well as the use of the river channel itself as a conduit for irrigation water. This has significantly changed salinity gradient patterns in the estuary.

The Kromme is a small system, which, despite a greatly reduced freshwater input because of dam construction, retains an open mouth because of the local coastal topography. The reduced freshwater supply has, however, resulted in a marine-dominated, clear water system totally different from the original estuarine community. Present research is dedicated to establish what levels of water released from the dam are required to maintain normal estuarine function. The Groot Brak is another small system which has been significantly impounded but has also been extensively investigated and manipulated in terms of modelling, water-release patterns and mouth breaching in order to protect housing developments in the lower reaches.

2.6.2 Sub-regional scale (see also Table 2.4 and Chapter 5)

(Those areas where determination between catchment and sub-regional scale was not meaningful have already been picked up in 2.6.1; contributing authors are the same as in 2.6.1).

1. North West Africa (see 2.6.1)

2. West Africa

Damming, deforestation and agriculture are considered to be the principal drivers of state changes at the coast through modifications of the hydrological regime, water quality and sediment discharge in the large catchments. These changes impact on the coastal system through erosion and sedimentation altering the coastal geomorphology; also changes in the quality and quantity of water flux resulting in salinisation, eutrophication and pollution, with consequent impacts on biodiversity/biological functioning, the introduction of aquatic weeds and human health. Each of these drivers is seen as having a major and progressive impact. Changes in water quality and, to some extent, quantity that have significant progressive impacts on the coastal system are also attributed to human settlement or urbanisation. Mining and particularly oil-related industrialisation, through their modification of the hydrological regime, make a substantial contribution to pollution and eutrophication among other water-related issues. The role of the natural driver climate change, through accelerated sea-level rise is regarded as becoming increasingly important in respect of coastal erosion, flooding and saline intrusion.

3. Congo (see 2.6.1)

4. South West Africa

The principal drivers considered responsible for minor-to-medium but progressive state changes and impacts at the coast are damming and agriculture, both causing modifications to runoff, water quality and coastal geomorphology. Their impacts at the coast include sedimentation, salinisation and habitat/biodiversity loss, and also, in the case of agriculture, pollution. Transport-related development is seen as causing changes to coastal habitat involving habitat/biodiversity loss. The natural driver climate change may be a significant contributor to erosion, sedimentation and salinisation. Other recognised coastal issues are eutrophication, pollution, aquatic weeds and human health. These are attributed not to human activities within the river basins, but rather to activities within the urban and industrial nodes on the coast itself. These are progressive, significant issues and matters of concern.

5. Nile

The Nile is a single-catchment sub-region. See 2.6.1 for the sub-regional assessment.

6. East Africa

Coastal erosion and sedimentation, pollution and loss of biological functioning are the principal impacts/issues concerning the medium catchments of this sub-region. Damming, deforestation and agriculture are the principal drivers and these are expected to become increasingly significant in respect of their impacts. However, information on the respective contributions of these drivers tends tends to be ambiguous and little is known of the critical thresholds. The possible contributory roles of urbanisation (coastal engineering) and natural (climate-related) drivers in coastal erosion and sedimentation need to be investigated. Agriculture is regarded as the principal catchment driver for the occurrence of pollutants at the coast though there are also significant inputs from coastal urban-industrial centres. Deterioration in biological functioning and loss of biodiversity as a consequence of an interplay of all the main drivers is a particular concern on this highly biodiverse but sensitive coral reef-fringed coast.

7. Central/southern Mozambique

The principal issues in this sub-region of medium and large transboundary catchments are the reduction in stream flow, coastal erosion, salinisation and nutrient depletion, all of which are attributed to the damming driver. No information on the critical thresholds for these impacts was identified by the workshop, though the severity of all the impacts is expected to increase. Eutrophication resulting from agriculture and urbanisation is stable to increasing, but is of concern only at the local scale. Biodiversity loss (or loss of biological functioning) is a significant issue ascribed to damming and agriculture, but as with eutrophication there is little information concerning critical thresholds and their indicators.

8. South East Africa

This sub-region is characterized by generally small catchments that are subject to various anthropogenic pressures, particularly water abstraction. Damming is an important driver, with freshwater retention in semi-arid conditions, and there are plans in place for further intensive damming. In the small basins this impoundment impacts directly on the coastal system, especially on estuarine environments, causing reduced freshwater inflow, nutrient depletion, salinisation and sediment accumulation in estuaries due to loss of freshwater scouring and extended periods of mouth closure. In extreme cases there may be no freshwater discharge throughout the year. Deforestation and poor agricultural practices have led to increased soil erosion and, especially in the small basins free from impoundment, there is an increasing problem of sediment discharge and siltation at the coast. Agriculture has also contributed to increased nutrient and pesticide fluxes resulting in local but progressive impacts of eutrophication and groundwater degradation at the coast. Urbanisation and industrialisation are the drivers responsible for the discharge of sewage and pollutants. These have high, sometimes direct though localised impacts near the coastal cities while coastal areas further distant retain relatively unaffected conditions.

Table 2.4. The link between coastal issues/impacts and land-based drivers in the coastal zone of Africa: overview and qualitative ranking on catchment and sub-regional scales.

Impact ranking scale, 1 = minimum, 10 = maximum

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Erosion	Damming	Sebou and Moulouya, Morocco	9	⇑	CNE (1995); Lahlou (1996); Haida (2000)
		Senegal, Senegal	5	⇒	Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996)
		Volta, Ghana	9	⇑	Kane (1997); Titriku (1998)
		Nile, mouths of Damietta and Rosetta distributaries, Egypt	8	⇑	Sestini (1992); Frihy & Komar (1993); Stanley (1996)
		Tana and Sabaki, Kenya	7	⇑	Dunne (1974, 1975); UNEP (1998); Denga *et al.* (2000)
		Rufiji, Tanzania	7	⇑	TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Zambezi, Mozambique	7	⇑	Gove (1993); Masundire & Matiza (1995)
		Incomati, Mozambique	6	⇑	JIBS (2001)
		Thukela, South Africa	2-3	⇒/⇑	Begg (1978)
		Great Fish/Kromme/Groot Brak, South Africa	2	⇒	see Ch.5 Table RA 8.1
	Deforestation	Sebou and Moulouya, Morocco	6	⇑	CNE (1995); Lahlou (1996); Haida (2000)
		Volta, Ghana	6	⇑	Kane (1997); Titriku (1998)
		Niger and Cross, Nigeria	8	⇑	AKS (1989); NEST (1989); Okoh & Egbon (1999)
		Tana and Sabaki, Kenya	7-8	⇑	Dunne (1974, 1975); UNEP (1998); Denga *et al.* (2000)
		Rufiji, Tanzania	7	⇑	TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Thukela, South Africa	2	⇒	Begg (1978)
	Agriculture	Sebou and Moulouya, Morocco	8	⇑	CNE (1995); Lahlou (1996); Haida (2000)
		Senegal, Senegal	7	⇒	Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996)
		Volta, Ghana	8	⇑	Kane (1997); Titriku (1998)
		Niger and Cross, Nigeria	8	⇑	AKS (1989)
		Thukela, South Africa	5	⇑	Begg (1978)

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Erosion Continued	Urbanisation	Sebou and Moulouya, Morocco	6	⇑	CNE (1995); Lahlou (1996); Haida (2000)
		Volta, Ghana	6	⇑	Kane (1997); Titriku (1998)
		Tana and Sabaki, Kenya	6-7	⇑	Denga *et al.* (2000)
		Thukela, South Africa	2	⇑	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak	3	⇒	
	Industrialisation	Tana, Kenya	5	⇑	Ewbank & Partners (1974)
		Thukela, South Africa	2	⇑	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak	2	⇒	
	Climate change	Nile delta, Egypt	8	⇑	Sestini (1992); Frihy & Komar (1993); Stanley (1996)
Sedimentation	Damming	Sebou and Moulouya, Morocco	9	⇑	Charrouf (1991); Snoussi *et al.* (2001)
		Volta, Ghana	7	⇒	Gordon (1998)
		Senegal, Senegal	9	⇑	Diaw *et al.*, (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996)
		Niger, Nigeria	6	⇑	NEST (1989)
		Gariep, South Africa	6	⇑	DWAF (1989, 1993)
		Olifants, South Africa	4	⇑	Huizinga & Van Neikerk (1997)
		Berg, South Africa	4	⇑	DWAF (1994)
		Tana, Kenya	8	⇑	ILACO (1971); Ewbank & Partners (1974)
		Sabaki, Kenya	5	⇑	Kairu and Nyandwi (2000)
		Zambezi, Mozambique	3	⇓	Gove (1993); Masundire & Matiza (1995)
		Incomati, Mozambique	2-3	⇓	
		Thukela, South Africa	3	probable ⇑	Begg (1978)
		Great Fish, Kromme, Groot Brak, South Africa	1-4	⇒	see Ch.5 Table RA 8.1

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Sedimentation Continued	Agriculture	Cross, Nigeria	6	⇑	NEST (1989)
		Gariep, South Africa	4	⇑	DWAF (1989, 1993)
		Olifants, South Africa	3	⇑	Huizinga & Van Neikerk (1997)
		Berg, South Africa	3	⇑	DWAF (1994)
		False Bay, Cape Town, S. Africa	3	⇑	Taljaard *et al.* (2000)
		Tana, Kenya	6	⇑	Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979); UNEP (1998); Denga *et al.* (2000)
		Sabaki, Kenya	7	⇑	Kairu and Nyandwi (2000)
		Rufiji, Tanzania	7	⇑	TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Zambezi, Mozambique	2	⇑	Gove (1993); Masundire & Matiza (1995)
	Deforestation	Sabaki, Kenya	7	⇑	Kairu and Nyandwi (2000)
		Rufiji, Tanzania	7	⇑	TCMP (2000, 2001); Ngusaru *et al.* (2001)
	Urbanisation	Table Bay/False Bay, Cape Town, South Africa	3	⇑	Quick & Roberts (1993); Taljaard *et al.* (2000)
Stream flow reduction	Damming	Zambezi, Mozambique	9		Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
		Limpopo, Mozambique	5	⇑	
Eutrophication	Sewage	Sebou and Moulouya, Morocco	9	⇑	
		Volta, Ghana	10	⇑	Mackinnon (1958); Finlayson (1998)
		Niger and Cross, Nigeria	7	⇑	NEST (1989)
		Nile, Egypt	?	?	EEAA (1996)
		Incomati, Mozambique	5	⇑	JIBS (2001); SRI (2001)
		Thukela, South Africa	3	⇑	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak, South Africa	1-4	⇒	
	Industrialisation	Saldanha Bay, South Africa	6	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
		Nile, Egypt	?	⇒	Awad (1994)
	Agriculture	Sebou and Moulouya, Morocco	8	⇑	
		Volta, Ghana	6	⇑	Mackinnon (1958); Finlayson (1998)
		Niger and Cross, Nigeria	7	⇑	NEST (1989)
		Nile, Egypt	?	?	Awad (1994)

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Eutrophication Continued	Agriculture continued	Limpopo, Mozambique	2	⇒	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
		Incomati, Mozambique	5	⇑	JIBS (2001); SRI (2001)
		Great Fish, Kromme, Groot Brak, South Africa	1-4	⇑	see Ch.5 Table RA 8.1
	Damming	Senegal, Senegal	4	⇑	UNEP (1999)
	Bushfires	Volta, Ghana	5	⇒	Mackinnon (1958); Finlayson (1998)
Pollution	Industrial and domestic waste	Sebou and Moulouya, Morocco	8	⇑	
	Urbanisation	Senegal, Senegal	?	⇑	
		Saldhana Bay, South Africa	4	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
		Table Bay, Cape Town, S. Africa	4	⇑	Quick & Roberts (1993); Monteiro (1997)
		False Bay, Cape Town, S. Africa	4	⇑	Taljaard (2000)
		Nile, Egypt	7	⇒	
		Tana and Sabaki, Kenya	5-6	⇑	
		Rufiji, Tanzania	7	⇑	Kulindwa (2000); TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Thukela, South Africa	3	⇒/⇑	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak, South Africa	1-3	⇑	
	Agriculture	Senegal, Senegal	?	⇑	
		Niger and Cross, Nigeria	7	⇑	NEST (1989); CRP (1999)
		Gariep, South Africa	2?	⇑	
		Olifants, South Africa	2?	⇑	Taljaard (1997)
		Berg, South Africa	2	⇑	DWAF (1994); Slinger & Taljaard (1994)
		Nile, Egypt	7	⇓	EEAA (1996)
		Tana and Sabaki, Kenya	6-7	⇑	Dunne (1974, 1975); Edwards (1979); Denga *et al.* (2000)
		Rufiji, Tanzania	6	⇑	Mwalyosi (1990) ; Kulindwa (2000); TCMP (2000, 2001)
		Zambezi	2?	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
		Incomati	8	⇑	Pers. comm.

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Pollution Continued	Industrialisation	Volta, Ghana	7	⇑	Amoah (1999)
		Niger and Cross, Nigeria	9	⇑	NEST (1989); AKS (1989); CRP (1999)
		Congo, Congo	3	?	
		Saldhana Bay, South Africa	4	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
		Table Bay, Cape Town, S. Africa	4	⇑	Quick & Roberts (1993); Monteiro (1997)
		Nile, Egypt	7	⇒	EEAA (1992)
		Tana and Sabaki, Kenya	4-6	⇑	
		Thukela, South Africa	3	⇑	
		Great Fish, Kromme, Groot Brak, South Africa	1-3	⇒	
	Mining	Volta, Ghana	7	⇑	Amoah (1999)
		Thukela, South Africa	3	⇒	see Ch.5 Table RA 8.1
	Fishing	Volta, Ghana	6	⇓	
		Rufiji, Tanzania	8	⇑	Bernacsek (1980); Boyd (1996); Kulindwa (2000); TCMP (2000, 2001)
Nutrient depletion	Damming	Great Fish, Kromme, Groot Brak, South Africa	5-8	⇑	see Ch.5 Table RA 8.1
Aquatic weeds	Active human introduction	Sebou and Moulouya, Morocco	6	⇑	Menioui (2001)
		Volta, Ghana	7	⇑	De Graft-Johnson (1999)
	Damming	Senegal, Senegal	9	⇓	Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); Matera & Malaisse (1999)
	Sewage	Sebou and Moulouya, Morocco	7	⇑	Menioui (2001)
		Volta, Ghana	7	⇑	De Graft-Johnson (1999)
		Table Bay, False Bay, S. Africa	4	⇑	Quick & Roberts (1993); Taljaard *et al.* (2000)
	Agriculture	Sebou and Moulouya, Morocco	6	⇑	Menioui (2001)
		Volta, Ghana	7	⇑	De Graft-Johnson (1999)
		Table Bay, False Bay, S. Africa	4	⇑	Quick & Roberts (1993); Taljaard *et al.* (2000)
	Bushfires	Volta, Ghana	7	⇒	De Graft-Johnson (1999)
	Transportation	Niger and Cross, Nigeria	7-8	⇑	NEST (1989); AKS (1989)

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Biodiversity loss	Multi-driver	Sebou and Moulouya, Morocco	8	⇑	GERM (1994)
		Volta, Ghana	8	⇑	Gordon (1999)
		Niger and Cross, Nigeria	7	⇑	NEST (1989); Ibeanu (2000)
		Tana and Sabaki, Kenya	7	⇑	see Ch.5 Table RA 6.1; Njuguna (1991); Raal & Barwell (1995); Knocker (1998)
		Rufiji, Tanzania	7	⇑	IUCN & Rufiji Administration (1997); Ngoile & Kiwia (1996); TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Thukela, South Africa	2-3	⇑	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak, South Africa	5-8	⇑	
	Damming	Senegal, Senegal	8	?	Ibeanu (2000)
		Gariep, South Africa	6	⇑	DWAF (1989, 1993)
		Olifants and Berg, South Africa	4	⇑	DWAF (1994); Huizinga & Van Niekerk (1997)
		Zambezi, Mozambique	7	⇑	Balon & Coche (1974); Brinca *et al.* (1986); Da Silva (1986); Gammelsrod (1992, 1996); Timberlake (1998)
	Deforestation	Congo, Congo	7	⇑	UNEP (1999); Morant (2001)
	Urbanisation	Congo, Congo	3	⇑	Morant (2001)
		Saldanha Bay, Table Bay, False Bay, South Africa	3-4	⇑	Quick & Roberts (1993); Monteiro & Largier (1999); Monteiro *et al.* (1999); Taljaard *et al.* (2000)
		Nile, Egypt	8	⇑	Hanafy (1998)
	Industrialisation	Congo, Congo	3	⇑	Morant (2001); Morant (pers. comm.)
		Saldanha Bay	3	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
		Nile, Egypt	?	⇒	Awad (1994)
	Agriculture	Gariep, South Africa	4	⇑	DWAF (1989, 1993)
		Olifants and Berg, South Africa	4	⇑	DWAF (1994); Huizinga & Van Niekerk (1997)
		Zambezi, Mozambique	7	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)

Table 2.4 continued

Coastal impact/issue	Driver	Local catchment		Trend expectations	References/data sources
		River	Impact Category		
Salinisation	Multi-driver	Sebou and Moulouya, Morocco	9	⇑	Moussaoui (1994); El Mandour (1995)
		Niger and Cross, Nigeria	7	⇑	
	Drought/climate change	Senegal, Senegal	5	⇑/⇒	Pages *et al.* (1987); Debenay *et al.*, (1994); BDPA-SCETAGRI *et al.* (1995); Diouf (1998)
	Damming	Gariep, Olifants, Berg, South Africa	4	⇑	DWAF (1989); Huizinga & Van Niekerk (1997)
		Incomati, Mozambique	8	⇑	SRI (2001)
	Agriculture	Gariep, Olifants, Berg, South Africa	3-4	⇑	DWAF (1989, 1993); Huizinga & Van Niekerk (1997)
Human health issues	Sewage	Sebou and Moulouya, Morocco	8	⇑	
		Senegal, Senegal	8	⇑	Handschumacher *et al.* (1992); Talla (1993); Niang (1999)
		Volta, Ghana	8	⇑	Derban (1999)
		Niger and Cross, Nigeria	7	⇑	NEST (1989); Ibeanu (2000)
		Table Bay and False Bay, South Africa	4	⇑	Quick & Roberts (1993); Taljaard *et al.* (2000)
		Nile, Egypt	8	⇓	Abo Zahra (2000)
		Rufiji, Tanzania	7	⇑	Wagner *et al.* (1998); TCMP (2000, 2001); Ngusaru *et al.* (2001)
		Thukela, South Africa	4-5	⇒	see Ch.5 Table RA 8.1
		Great Fish, Kromme, Groot Brak, South Africa	3-7	⇒/⇑	
	Damming	Senegal, Senegal	8	⇑	Handschumacher *et al.* (1992); Talla (1993); Niang (1999)
	Industrialisation	Saldanha Bay, South Africa	4	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
		Nile, Egypt	8	⇒	EEAA (1992, 1996)
	Agriculture	Nile, Egypt	?	⇓	Awad (1994)

2.6.3 Regional scale (see Table 2.6)

A first-cut ranking order was drawn up for Africa, together with expected future trends in impacts (see Table 1.1). It should be recognised that the ranking given here attempts to create a full regional picture, although, medium-ranked statuses can become major ones if catchments of specific size classes are considered.

Coastal geomorphological change involving erosion and sedimentation was identified as a significant and progressive impact in nearly all of the sub-regions, the problem being acute on the Nile delta and in the West African lagoon systems. Damming was viewed as the principal driver in such change, with consequent reductions in stream flow and sediment flushing. Damming was also seen as being largely responsible for coastal salinisation, e.g., the Incomati estuary in Mozambique and nutrient depletion in the coastal sea, e.g., KwaZulu Natal. In most sub-regions deforestation and agriculture were regarded as important drivers, particularly in respect of coastal sedimentation from medium and small catchments, e.g., the Tana and Sabaki in Kenya. Human settlement was identified as a major contributor to eutrophication and the incidence of aquatic weeds in the large West African catchments. Elsewhere, while eutrophication and pollution were recognised, they were mostly related to coastal urban-industrial sources, e.g., Alexandria, Mombasa, Saldanha Bay and Cape Town. Loss of biodiversity or biological functioning was seen as another common issue, though related to complex ranges of human and natural drivers.

In general these data are characteristic of developing economy situations where economic growth and water use exceed development of the necessary urban and industrial infrastructure. This finding parallels those made in the South American (SAmBas), and East Asian Basins assessment and synthesis processes (de Lacerda *et al.* 2001; Hong *et al.* in prep.). However, heterogeneity of the sub-regions seems to be more pronounced in Africa than in other world regions, making the ranking of issues and drivers in Africa a more complex challenge.

Table 2.5 Summary of priority driver/pressure features by country, corresponding "hot spots" and information available in Africa (see also Section 2.6.5).

Country	Driver/Pressure	Hot spots	Available information
1. Morocco	• Damming • Human settlement, agriculture and industrialisation	• Sedimentation through reduced flushing especially on Mediterranean coasts; salinisation of coastal plains • Eutrophication, pollution on Mediterranean and Atlantic coasts	• Etat de qualité des Ressources en eau au Maroc (DRPE 1998) and many published papers and reports
2. Senegal	• Damming • Human settlement	• Sedimentation, invasion by aquatic weeds and loss of biodiversity in Senegal river; estuarine ecosystem destroyed • Human health issues	• Barrage-related impact studies, water quality assessments
2. Ghana	• Damming • Human settlement	• Erosion of Volta delta and invasion by aquatic weeds • Eutrophication and human health issues in Volta	• Lower Volta environmental impact study (VBRP 1996-2001); Coastal wetland management project (1992-1997) GEF; Integrated coastal zone management strategy (World Bank 1996)
2. Nigeria	• Industrialisation	• Oil-related pollution in Cross and Niger	• World Bank studies, 1995; Moffat & Linden (1995)
4, 8. South Africa	• Damming and diversion • Urbanisation and industrialisation	• Nutrient depletion off sourth-east coast with resulting biodiversity loss; sedimentation and loss of habitat on southwest coast • Eutrophication and pollution at Saldanha Bay	• Estuarine studies since 1950s; summary of available estuarine literature and the synthesis of available knowledge • CSIR monitoring and modelling programmes initiated
5. Egypt	• Damming and diversion • Urbanisation and industrialisation	• Erosion of Nile delta • High levels of pollution and eutrophication in Abu Qir Bay, Mex Bay and on Alexandria city coast	• Shoreline monitoring • Water quality monitoring
6. Kenya	• Damming • Deforestation	• Deterioration in Tana water quality • Siltation at mouth of Sabaki	• Fish stock and biological productivity data • Coral impact data
6. Tanzania	• Deforestation • Agriculture • Aquaculture	• Siltation at mouth of Rufiji • Deterioration of Rufiji water quality • Pollution from prawn fisheries	• Biodiversity data for mangrove and coral areas • EIA reports
6,7. Mozambique	• Damming and abstraction	• Biodiversity loss in Zambezi delta and on Sofala Bank • Salinisation of Incomati • Erosion of Zambezi delta	• Fish stock and biological productivity data • Incomati hydrology study

Table 2.6 Major activities (drivers), present status and trends affecting the coastal zone of Africa.

Anthropogenic drivers	Major state changes and impact	Location	Present status	Trend expectations	Major areas affected (figures refer to sub-regions)
Damming Diversion	Erosion	West coast	Major	Increasing	2. Senegal, Volta, Niger
		Nile delta	Major	Increasing	5. Nile delta distributaries
		East coast	Medium	Increasing	7. Zambezi
	Sedimentation	West coast			
		Nile delta	Local	-	5. Nile delta
		East coast	Local	Increasing	6. Malindi coast, Kenya
	Salinisation	West coast	Medium	Increasing	1. Moulouya, 2. Niger delta
		Nile delta	Medium	Increasing	5. Nile delta
		East coast	Medium	Increasing	6. Tana, 7. Incomati
	Nutrient depletion	West coast			
		Nile delta	-	-	
		East coast	Medium	Increasing	7. Southern Mozambique, 8. KwaZulu-Natal
Various drivers	Biodiversity loss	West coast	Major	Increasing	Almost all sub-regions
		Nile delta	Major	Increasing	
		East coast	Major	Increasing	
Deforestation	Erosion	West coast	Medium	Increasing	Medium ranking for most sub-regions, however, major for coastal impacts generated in small and medium catchments in 1 and 6
		Nile delta	-		
		East coast	Medium	Increasing	
	Sedimentation	West coast	Medium	Increasing	
		Nile delta	-		
		East coast	Medium	Increasing	

Table 2.6 continued

Anthropogenic drivers	Major state changes and impact	Location	Present status	Trend expectations	Major areas affected (figures refer to sub-regions)
Agriculture	Sedimentation	West coast Nile Delta East coast	Minor - Medium	Increasing - Increasing	2. Cross, 4. Gariep, Olifants, Berg 6. Tana, Sabaki, Rufiji
	Eutrophication	West coast Nile delta East coast	Medium - Medium	Increasing - Increasing	Medium ranking for most sub-regions, but major for coastal impacts generated in small and medium size catchments in 1 and 6
	Pollution	West coast Nile Delta East coast	Medium Major Medium	Increasing Decreasing Increasing	
Urbanisation	Eutrophication	West coast Nile delta East coast	Medium Major Medium	Increasing Increasing Increasing	Medium overall but major in 5
Industrialisation	Pollution	West coast Nile delta East coast	Medium Major Medium	Increasing Increasing Increasing	As above, but in most cases more coastal than catchment-based – 4 , 5, 6

2.6.4 Policy, scientific and management responses (see Table 2.7 and Chapter 5).

There is a growing awareness by scientists, managers and policy makers of the need to understand coastal systems in the context of their related catchments so that knowledge of the linkages between human activities in river catchments and environment-related socio-economic issues at the coast can feed into effective integrated management. While the coast and coastal seas have long attracted scientific and socio-economic research, there has been a tendency worldwide, but perhaps particularly in Africa, for that research to be sectoral, with somewhat limited application in integrated management.

The last decade or so has seen a worldwide shift towards research and management initiatives that take a broader view of land-sea interaction in both space and time. Such linked projects cover present (and past) material fluxes between the land and the ocean via rivers and lakes, groundwater, the atmosphere and coastal seas. This broadening of perspective has been accompanied by the realisation of the importance of socio-economic as well as natural factors as drivers of system changes in the coastal environment. Scientific and management responses to the need for this more integrated approach to understanding and managing the coastal resource with its complex ecosystem are becoming increasingly apparent in the region. Regional/global scientific responses include the UNEP GEF Global International Waters Assessment (GIWA), and increasingly these show a trend towards initiatives that view catchments and coasts in integrated system contexts. In general policy responses at the regional level remain in the process of formulation. Listings and brief descriptions of the initiatives, both scientific and management, developed both for catchments and sub-regionally are presented in Table 2.7.

1Table 2.7 Scientific and/or management responses to coastal impact/issues in the African coastal zones on catchment, sub-regional and regional scales

River catchment	RESPONSE Catchment scale		RESPONSE Sub-regional scale – North-west Africa		RESPONSE Regional scale	
MOROCCO	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Sebou	-Atlas du Sebou (1970) -Etat de qualité des Ressources en eau au Maroc (DRPE, 1998). - Diagnose de l'Etat de l'environnement dans le bassin du Gharb (Benasser, 1997) Bilan des flux du Sebou (Haida, 2000)	The 'Office Régional de Mise en Valeur Agricole du Gharb' (ORMVAG) is in charge of the management of the Sebou basin. The Waters and Forests Department and the department of Environment have carried out many projects in the basin, among them the rehabilitation of the Sebou Basin Project.	- Med Campus Project (UE). *«Gestion des réserves d'eau souterraine dans les zones affectées par la salinisation».1994.* -Avicenne Project (UE):*«Development of water resources management tools for Problem of seawater intrusion and contamination of fresh-water resources in coastal aquifers». 1995-1999.* -FICU Project: (F*ond* I*nternational de Coopération* U*niversitaire): 'Gestion et protection des ressources en eaux dans les plaines semi-arides au Maroc et en Tunisie.2000-2002'.* MATER Project ADIOS Project	Guidelines for Integrated Coastal Zone Management in the Mediterranean Region (UNEP 1995) • L'eau dans le basin Mediterranéen (Economica) (Margat 1992)		
Moulouya	Many reports and papers on how to combat siltation of dams, soil erosion and salinisation in the basin	Aménagement du bassin de la Moulouya (Eaux et Forets, in press)				

Table 2.7 continued

River catchment	RESPONSE Catchment scale		RESPONSE Sub regional scale - West Africa		RESPONSE Regional scale	
SENEGAL	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Senegal	Michel *et al.* (1993) L'Apres Barrage dans la vallee du Senegal. EQUESEN (1993) Environnement et Qualite des Eaux du Fleuve Senegal. SEAH (1996) Transformation des Hydrosystemes lies aux grands barrages en Afrique soudanienne et sahelienne. BDPA (1996) Bilan Diagnostic du Delta du Senegal	OMVS (Organisation pour la mise en valeur du fleuve Senegal) Initiatives to combat the invasion by macrophytes; others to combat inundations Danish Project for the elaboration of an integrated management of the delta	Large marine ecosystem Gulf of Guinea Project (1995-2001) UNIDO-GEF Transboundary diagnostic analysis for the Volta Basin UNEP-GEF (ongoing) Mahe (1993) – study referring to all basins discharging to the Atlantic Ocean	Large marine ecosystem Gulf of Guinea Project (1995-2001) UNIDO-GEF Transboundary diagnostic analysis for the Volta Basin UNEP-GEF (ongoing)		
GHANA						
Volta	Ghana water resources management study (1998). Lower Volta environmental impact study (VBRP 1996-2001). Ghana coastal wetland management project (1992-1997) GEF. Integrated coastal zone management strategy for Ghana (World Bank 1996).	Ghana water resources management study (1998). Lower Volta environmental impact study (VBRP 1996-2001). Ghana coastal wetland management project (1992-1997) GEF. Integrated coastal zone management strategy for Ghana (World Bank 1996).				

Table 2.7 continued

River catchment	RESPONSE Catchment scale		RESPONSE Sub-regional scale		RESPONSE Regional scale	
NIGERIA	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Niger	Environmental Diagnostic Studies (NDES 1997). Niger Delta Development Cooperation (NDDC 2001).	Environmental Diagnostic Studies (NDES 1997). Niger Delta Development Cooperation (NDDC 2001). Federal Environmental Protection Agency (FEPA). Federal Ministry for Environment				
Cross	Control of pollution, flood in the Cross river Basin (CRBDA, 1976). Environmental Inventory survey (AKS 1989).	Federal Environmental Protection Agency (FEPA). Control of pollution, flood in the Cross river basin (CRBDA 1976). State Minister of the Environment (AKS 1989)				
CONGO						
Congo	?	Provision of technical support to the Dem. Rep. of the Congo through the Min. of the Environment and Tourism given to allow it to prevent and/or reduce degradation of the coastal environment caused by land-based activities (UNEP, 1999).				

Table 2.7 continued

River catchment	RESPONSE catchment scale		RESPONSE Sub- regional scale – South Africa		RESPONSE Regional scale	
S. AFRICA	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Gariep	-	-	-	• The National Water Act of South Africa (Act 36 of 1998) states that the natural environment has a right to water. As a result, the quantity and quality of water and other resource quality objective need to be determined for river catchments. The national Department of Water Affairs and Forestry are responsible for setting the 'Reserve and Resource Quality Objectives' for catchments, including estuaries. To facilitate implementation of these measures, the law requires that Catchment Management Agency (CMA) and Catchment Management Forums be put in place for each basin.		
Olifants	-	-				
Berg	CSIR's catchment-2-coast initiative in this area	Department of Water Affairs and Forestry to initiate a monitoring programme in the area				
Saldanha Bay	Joint CSIR – Marine and Coastal Management (Department of Environmental Affairs) Project (Monteiro & Largier 1999)					
Table Bay	-	-				
False Bay	Review on anthropogenic inputs undertaken in 2000 (Taljaard *et al.* 2000)	-				

Table 2.7 continued

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional scale		RESPONSE Regional scale	
EGYPT	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Nile	Nile water quality monitoring. Coastal water quality monitoring. Pollution impact assessment on Nile and marine resources. Pollution hot spot monitoring. Sea-level rise monitoring.	Legislation and enforcement measures since 1994. Creation of EEAA. (Egyptian Environmental Affairs Agency) and its 8 Regional Branches. National CZM plan and committee. Implementation of national programmes for: -Nile water monitoring -Shoreline protection and planning -GIS database -Domestic/industrial waste treatment	MedPol programmes MedGOOS monitoring Environmental Information Monitoring Programme	MAP/UNEP MAMA/IOC EIMP/DANIDA	MedPol programmes MedGOOS monitoring	MAP/UNEP MAMA/IOC

Table 2.7 continued

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional scale		RESPONSE Regional scale	
KENYA	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Kenya coast including Tana and Sabaki (Athi, Galana) river basins	EU-STD II-III and EU-RTD IV project, IOC-SAREC, UNEP-UNESCO, NWP-KWS, Tana Primates World Bank-GEF	Coast Province Adminstration, District Development Planning, Local Gvernment Authorities, Tana and Athi Rivers Development Authority	UNEP-BADC Eastern Africa Atlas of Coastal Resources – Kenya (1998); Tanzania (2001). IOC-UNESCO Guidelines for the study of shoreline change in the Western Indian Ocean Region (Kairu & Nyandwi 2000). Establishment of IOC Western Indian Ocean regional office in KMFRI, Mombasa.	National Environment Management Council (NEMC), Tanzania. Coast Development Authority, Kenya. Kenya Wildlife Service.		
TANZANIA						
Rufiji	NEMC,TCMP - GISD project (USAID) REMP (IUCN) RUBADA Mangrove management project (NORAD) FRONTIER University of Dar es Salaam RIPS (FINIDA). WWF-Ecoregion project Sida-SAREC Rufiji Flood Plain Project (Ireland and Netherlands)	Rufiji Basin Development Program Rufiji Environmental Management Program Mangrove Management Program Marine and Coastal Research Rural Integrated Program Support Coastal Forest Conservation Rufiji Flood Plain Project Biodiversity Loss EIA for Damming Pestsides and Agrochemical impact on coastal environment Impact of Industrial effluents through Rufiji River to the coastal environment Socio-economic impact Assessment				

Table 2.7 continued

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional
MOZAMBIQUE	**Scientific**	**Management**	
Incomati	Shared River Initiative Project. RSA. (1999 – 2000) Joint Inkomati Basin study, phase 1-2. Consultec and BKS Acres, Final Report (2001) Country situation Report – Water Resources – Mozambique vol.1-3- (1998) MBB Consulting Engineers, Acer (Africa) Environmental Management Consultants, AWARD 2000. Proposal for the Establishment of Catchment Management Agency for the Inkomati Basin. Final draft prepared for the Inkomati Catchment Management Agency Reference Group, under the auspices of DWAF, Mpumalanga Regional Office. (2000) **DNA**. 1991 Gestao de Recursos Hidricos na Bacia Hidrografica do Incomati. Report 56/91	Shared River Initiative Project. RSA. (1999 – 2000) Joint Inkomati Basin study, phase 1-2. Consultec and BKS Acres, Final Report (2001) Country situation Report – water Resources – Mozambique vol.1-3- (1998). The first phase of a cumulative environmental impact assessment for the Inkomati river basin. (2000) MBB Consulting Engineers, Acer (Africa) Environmental Management Consultants, AWARD 2000. Proposal for the Establishment of a Catchment Management Agency for the Inkomati Basin. Final Draft. Prepared for the Inkomati; Catchment Management Agency Reference Group, under the auspices of DWAF, Mpumalanga Regional Office. (2000) **DNA**. 1991. Gestao de Recursos Hidricos na Bacia Hidrografica do Incomati. Report 56/91	
Limpopo	Jamieson, J.G. Planning and management of water resources in Mozambique. DNA (1985) Koudstaal, R. Identification of major issues in Water resources master planning in Mozambique. Delft, Netherlands (1989) DNA, Planning for water resources management. Progress Limpopo Study. Maputo (1991)	Jamieson, J.G. Planning and management of water resources in Mozambique. DNA (1985) Koudstaal, R. Identification of major issues in Water resources master planning in Mozambique. Delft, Netherlands (1989) DNA, Planning for water resources management. Progress Limpopo Study. Maputo (1991)	

Table 2.7 continued

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional scale	
SOUTH AFRICA	**Scientific**	**Management**	**Scientific**	**Management**
Thukela	Incorporation of estuary as well as coastal and offshore environments into the E.I.A. of the proposed T.W.P. (Thukela Water Project) by the South African Department of Water Affairs and Forestry. Report in press	Proposed consideration of the design of the impoundments and water release patterns to allow minimum disruption of natural flow patterns	Marine processes dominate the very open, high energy South African coastline, with the result that catchment events are far more apparent in estuaries than offshore, although turbidity plumes are a feature of the KwaZulu Natal coast during the summer rainfall period. Consideration of the effects of land runoff have not been a priority until very recently, culminating in the T.W.P. E.I.A. referred to in this table. Marine research dates back at least a century while organized estuarine studies only began in about 1950 (Day 2000). For reasons outlined above the estuarine research component shows far more focus on the land-water interaction and this is reflected in Whitfield's (2000) summary of available estuarine literature and the synthesis of available knowledge by Allanson & Baird (1999).	Estuarine studies have, in recent years, focussed progressively more on management objectives, practicalities and techniques and have been fortunate in being able to build on a strong research foundation. The incorporation of this knowledge into management policy and action is now a major priority. Research and management is strongly supported by local funding agencies including the Department of Environmental Affairs and Tourism, the National Research Foundation, The Water Research Commission and the Department of Water Affairs and Forestry (at times with European and British subvention). These organizations work closely with the Consortium for Estuarine Research and Management (CERM) a voluntary network of about 80 researchers working on estuaries throughout the country (For review see SA Waterbulletin 27(6)). A significant attempt to bring estuarine science to the manager has been produced by Breen & McKenzie (2001) which incorporates a summary of the relevant legislation which provides for protection of both the estuarine and the coastal environment. Legislation is covered in more detail by Glazewski (2000)and policy and implementation is reviewed by Boyd *et al.* (2000), Glavovic (2000) and the Department of Environmental Affairs & Tourism (2000).

2.6.5 Key areas for research projects (see Table 2.8 and Chapter 5)

Data

A scarcity of relevant data is a recurrent problem in most sub-regions, for scientific data but particularly for socio-economic information, and for both activities in the catchments and impacts at the coast. Time-series data generated from routine monitoring programmes is particularly sparse. In some cases older data may exist though these are yet to be accessed. The collection of standardised data relating to the large transboundary catchments presents considerable challenges. The workshop recognised the need to incorporate or initiate basic data collection and monitoring within any proposed integrated regional research programme. Data collection programmes should be designed as far as possible with the aim of establishing the causes of changes in the coastal environmental state that impact upon the coastal resource, whether those causes are natural, anthropogenic or a combination of the two.

Indicators

The workshop highlighted a considerable lack of knowledge about the critical loads and thresholds of material fluxes passing from the catchments to (or through) the coastal area to the coastal sea that, if exceeded, would significantly change the coastal environment. There is a need for common parameters to be established in respect of the indicators of change that are relevant to the region. Such an approach should take into account not only the incidence of a change of state but its spatial and temporal dimensions as well, bearing in mind the coastal type (geomorphology and oceanography) and its capacity for the retention of catchment-derived materials or their dispersal to the ocean.

Research challenges

Supposed 'multi-driver' impacts pose a major challenge, particularly in medium and large, transboundary catchments, where there is scope for substantial transformation or reduction of material fluxes within the system. In many sub-regions the loss of biodiversity or loss of biological functioning was ascribed to a suite of drivers, so that an appropriate, targeted response policy may be difficult to formulate. The specific contributions (positive or negative) to the fluxes of water and sediment that reach the coast arising from, e.g., agricultural practices, deforestation or damming need especially careful analysis, bearing in mind the socio-economic implications of regulation in these areas. In the AfriBasins process the rates of changes in the coastal environmental state resulting from catchment-generated pressures were assessed only in general terms – 'direct' or 'progressive'. In some cases there was uncertainty in the assessment. To prioritise appropriate responses in the catchments at management and policy levels, t more specific information is necessary on rates of change and time-lags between the anthropogenic pressure and the corresponding change to the state. An integrated regional research programme would provide the opportunity for the comparison of pressure-state changes in catchments of different sizes in a variety of geographical settings within the region.

The contributions that natural drivers such as climate change have made andwill make to the state of the coastal environment over a range of time-scales is another area for consideration by regionally integrated research. For example, sporadic extreme event cyclonic flooding is a feature of catchments in central/southern Mozambique, with major fluxes of water and sediment causing widespread coastal change and socio-economic disruption. Thus, the coastal impacts of human activities in catchments need to be set in the context of natural driving forces. Similarly, the effects of sea-level rise and/or (perhaps short-term) variability of the coastal climate as possible contributors to changes in coastal geomorphology and estuarine salinisation need to be considered if the contributions to change resulting from anthropogenic catchment activities are to be properly assessed. Changes occurring over the longer (historical and pre-Anthropocene) term are subjects of research under the IGBP-PAGES core project (Past Global Changes).

The coastal sea of Africa also receives significant nutrient and pollutant discharge from urban-industrial centres along the coast. Research is needed in a range of geomorphological and oceanographic settings to assess and quantify the impacts of such coast-generated pollution and eutrophication for comparison with the impacts ascribed to catchment drivers. The maintenance of groundwater resources to support coastal communities in the face of diminishing recharge from catchments and (coastal) abstraction-induced (marine) saline intrusion is another priority issue of regional importance to be addressed by an integrated research programme.

Table 2.8 "Hot spots" of land-based coastal impact and gaps in understanding as well as the first overview of issues to be addressed in future research.

River catchment	Hot spot Catchment scale		Hot spot Regional scale	
	Key issues, trend and gaps	**Scientific approach**	**Key issues, trend and gaps**	**Scientific approach**
Sebou and Moulouya, Morocco	Increasing erosion/sedimentation, pollution/health issues, salinisation and biodiversity loss	Monitoring water and sediment fluxes, and water quality parameters. Development of adequate environmental indicators and precise critical thresholds.	Erosion Sedimentation	Measurement of slopes, speed of runoff and sediment loads Measurements of sediment loads
	Additional data are required to improve the calculations of natural and anthropogenic fluxes, to better understand the functioning of the estuarine zones and to predict the future potential changes.	Establishment of socio-economic profiles in relation to population changes, industrialisation, agriculture and forestry, and development of economic cost-benefit analysis. Development of numerical models and GIS in relation to future land-use and climate changes, easily readable by managers.	Pollution Pesticides Aquatic weeds including invasive plant species Loss of habitat/ Biodiversity Human Health issues	Monitoring water quality parameters/use of questionnaires Assessment of species population Assessment of river biodiversity Socio-economic studies/ questionnaire administration

Table 2.8 continued

River catchment	Hot spot Catchment scale		Hot spot West Africa sub-regional scale	
	Key issues, trend and gaps	**Scientific approach**	**Key issues, trend and gaps**	**Scientific approach**
Senegal, Senegal	Coastal changes	Use of aerial photographs and satellite images Monitoring of the Langue de Barbarie sand spit	Erosion	Measurement of slopes, speed of runoff and sediment loads
	Sediment and chemical fluxes	Field work with sampling sites		
	Control of pollutants (pesticides and fertilizers)	Sampling and analysis of water samples	Sedimentation	Measurements of sediment loads
	Inundation control	Monitoring of the technical structures (sand bags mainly) and their efficiency	Pollution Pesticides	Monitoring water quality parameters/use of questionnaires
Volta, Ghana	Erosion	Measurement of slopes, runoff speed and sediment loads		
	Sedimentation	Measurements of sediment loads	Aquatic weeds including invasive plant species	Assessment of species population
	Pollution Pesticides	Monitoring water quality parameters in the Volta Lake/use of questionnaires	Loss of Habitat/ Biodiversity	Assessment of river biodiversity
	Aquatic weeds including invasive plant species	Assessment of species population	Human Health issues	Socio-economic studies/ questionnaire administration
	Loss of habitat/ biodiversity	Assessment of river biodiversity		
	Human Health issues	Socio-economic studies/questionnaire administration		

Table 2.8 continued

River catchment	Hot spot Catchment scale	
	Key issues, trend and gaps	**Scientific approach**
Niger, Nigeria	Water pollution	Studies of water quality
	Invasion by exotic weeds (nypa palm and water hyacinth)	Assessment of the impact of nypa palm and water hyacinth on aquatic population and rural livelihood
	Oil spillage	Assessment of impact of oil spillage on the environment
	Silting	The study of extent an impact of silting on the coastal environment
	Health problems	Study of the impact of environmental pollution on human health
Cross, Nigeria	Beach erosion	Study of the extent of impact of beach erosion on coastal environment
	Nypa palm invasion	Assessment of impact on biodiversity
	Oil pollution	Assessment of extent and effects of oil pollution on environment and people's livelihood
	Biodiversity loss	Study of biodiversity loss
	Earth tremors	Geological studies of coastal and oil-producing community

Table 2.8 continued

River catchment	Hot spot Catchment scale	
	Key issues, trend and gaps	**Scientific approach**
Gariep, South Africa	Impacts of altered freshwater inflow (and possibly also reduced sediment input), as a result of damming and agricultural use, on the coast (as well as associated industries such as diamond mining and fishing) has not been established	Monitoring required to determine the extent and severity of current impacts on the coast and to establish linkages with catchment-derived drivers Predictive capabilities currently applied in other southern African catchments be implemented and adapted for the Gariep to provide scientific support underpinning effective management
Berg, South Africa	Changes occurred in the hydrological regime (reduction in inflow) and geomorphology due to upstream damming Further damming is under consideration Additional data are required to predict the extent, severity and implication of damming with greater confidence	The Department of Water Affairs and Forestry is in the process of initiating an extensive monitoring programme The CSIR is developing numerical tools (through the catchment-to-coast initiative) to provide sound scientific predictive capabilities essential for effective management of coastal issues
Saldanha Bay, South Africa	Increasing urbanisation and industrialization results in impacts such eutrophication and pollution. Extensive research studies have already provided valuable scientific understanding, but these need to be transformed into effective, practical management plans to address issues.	The Saldanha Bay Water Quality Forum has been established to coordinate management efforts towards addressing key issues The CSIR has set up sophisticated hydrodynamic and water quality numerical models to provide sound scientific predictive capabilities essential for effective management of the area

Table 2.8 continued

River catchment	Hot spot Catchment scale	
	Key issues, trend and gaps	**Scientific approach**
Nile, Egypt	River water quality Loss of fisheries Pollution Erosion Land-filling	Biogeochemical studies especially in coastal lagoons Modelling of hazardous substances dispersion in coastal waters Assessment of pollution receiving water assimilation capacity River, lagoons and coastal living resource management Biodiversity Shoreline protection/planning management Pollution control management Stakeholders awareness
Tana, Kenya	Hydrology, hydrodynamics and water circulation Deterioration of water quality River and marine biodiversity loss Population dynamics of the key fisheries Socio-economic situations	Measurements and modelling studies - river discharge dynamics, sediment loads and water exchange in the estuary Monitoring water quality parameters in the Tana delta Assessment of river and marine biodiversity Assessment of dynamics of key commercial species Study existing socio-economic set-up in the river basin and along the coastal zone
Rufiji, Tanzania	Nearshore oceanography and coastal processes Hydrogeology Sedimentation and water quality related problems River and marine biodiversity loss and conservation Trade dynamics of natural resources Agriculture and livestock development and impact on the environment Mangrove and estuarine dynamics Relation between fisheries and the flooding regime Dynamics of the natural forests and woodlands Identification of urgent conservation measures	Fundamental research to support the understanding of intricate ecological processes, which is the key to defining sustainability Applied research with case studies of processes (of specific issues or problems of the dynamics) Predictive models (natural and human-induced ecosystem changes) Monitoring and feasibility studies Flows – which include materials, and elements through the system (pollutants, DDT, nutrients, water) Stocks – in terms of quantity of environmentally provided assets such as forests, wildlife, fisheries, water, wetlands, soil, atmosphere. These provide a flow of useful goods or services. Status – in terms of measures of specific phenomena (e.g., levels of land based inputs to the sea, carrying capacity, water requirements for the survival of ecosystems, health etc.)

Table 2.8 continued

River catchment	Hot spot Catchment scale		Hot spot Central/southern Mozambique sub-regional scale	
	Key issues, trend and gaps	**Scientific approach**	**Key issues, trend and gaps**	**Scientific approach**
Zambezi, Mozambique	Investigate effects of upstream impoundments and flood regulation on the Mozambique coast Impact of the cessation of silt transport to the Mozambique coast Impact of nutrient retention on bio-productivity	Monitoring and investigative research	Deterioration of water quality River and marine biodiversity loss	Monitoring water quality parameters in Maputo Bay Assessment of river and marine biodiversity
Limpopo, Mozambique	Floods regulation Water quantity Water quality	Identification of flood plain risk in coastal zone. Monitoring water quality and biodiversity loss. Studies of river health.		
Incomati, Mozambique	Water quantity Water quality River and marine biodiversity loss Salt intrusion Socio-economic situations	Assessment and modelling studies river health. Monitoring water quality parameters in Incomati Assessment of dynamics of salt intrusion and land loss Study existing socio-economic set-up in the river basin and along the coastal zone		

Table 2.8 continued

River catchment	**Hot spot Catchment scale**	
	Key issues, trend and gaps	**Scientific approach**
Thukela, Mkomazi and other major east coast rivers in South Africa	Effects of land derived runoff on coastal marine productivity in oligotrophic coastal environments	Primary production studies in the water column; effects of floods, sediment plumes on biological processes in affected areas
Rivers (Mkuzi, Mfolozi, Hluhluwe) associated with the Greater St Lucia Wetland Park (a Ramsar site), South Africa	Long-term effects of flow reduction and droughts on biological processes in the St Lucia Lake.	Analysis of nutrient sources and cycles; levels of primary production in the water column and fringing vegetation; effects of different salinity levels on carbon fixation and sources, carbon and nitrogen flow patterns based on light isotope analyses

3. OUTLOOK AND PROJECT IDENTIFICATION

by H.H. Kremer, R.S. Arthurton and Wim Salomons

3.1 The AfriCat framework

From the results of the DPSIR assessment, the workshop identified river catchments within the region for proposed detailed study, examining various aspects of the driver-impact linkage. This output would feed the planned "AfriCat" proposal, envisaged as providing a conceptual umbrella covering individual study proposals, that will be developed concurrently by the AfriBasins scientists' network. The broad principles of AfriCat will be similar to those of the established "EuroCat" (http://www.iia-cnr.unical.it /EUROCAT /project.htm).

There would be an integrated, systematic approach to the understanding of the water cascade, taking the catchments and the coast as single systems, with robust science and emphasis on relevant data-building and communication. The workshop recognised that the studies must add value to existing work, have a strong socio-economic input and show how the needs of a clearly identified user community were being addressed. Some projects are likely to focus on biological resilience in estuaries or the coastal sea, identifying the critical thresholds and indicators of acceptable change. In some cases there may be opportunities to build upon existing projects, extending their scope and thus providing a more comprehensive and integrated picture of the catchment-to-coastal sea linkage. As well as serving local and regional needs, the integrated studies of AfriCat will also feed the global aims of Earth System Science, through the provision of reliable bases for up-scaling in a region where, compared with Europe in particular, recent and reliable data are very sparse.

3.2 Regional needs and linkages

The AfriCat proposal will have an emphasis on addressing the regional African needs, in the context of priority areas for action as identified by the African Ministerial Conference on the Environment (AMCEN) in preparation for the World Summit on Sustainable Development in Johannesburg, September 2002. Potential links between the AfriBasins/AfriCat activities under LOICZ with the joint ACOPS (Advisory Committee for the Protection of the Sea) – UNESCO'S IOC GEF – MSP project 'African Process' for the "Development and protection of the coastal and marine environment in sub-Saharan Africa" were the subject of fruitful talks at the Rio+10 meeting of the IOC in December 2001 in Paris. This is being followed up by the LOICZ participation at the second meeting of the Working Group on the Programme of Interventions (WGPI-II). LOICZ has agreed in principle to channel the AfriBasins work and the AfriCat draft (design and methodologies) into the African Process, which already has the full political endorsement of at least 11 countries in the region and will feed into the Johannesburg conference.

The need for innovation and shared experience between sites to make the most effective use of limited funding was accepted by the workshop; this would include improved data transfer within the region, long-term surveillance of the environment and building human capacity and institutional structures in coastal science. The workshop envisaged AfriCat as encompassing themes that would be attractive to specific donors. Most importantly, the goal of AfriCat must be to improve the lives of coastal communities in the context of the catchment-to-coast system. There was considered to be great potential benefit in linking rivers and coasts at the scientific, policy and management levels. Improving management was a crucial goal and the challenge for the scientists was to produce a sound information base that was accessible and understandable to the management community at local as well as more regional levels, e.g., Southern African Development Community (SADC). To be successful, AfriCat must be owned by national governments. UNEP-ROA, through the AMCEN process, will assist to promote such ownership and endorsement by providing a platform to distribute and communicate the AfriBasins results and project developments to the regional governments. LOICZ itself can be only the initiator of project development, drawing together the regional scientific network and facilitating the provision of international links.

3.3 Project focus and organisation

In accepting the need to adopt an African perspective of catchment-coastal impact problems the workshop recognised the broad diversity of coastal situations within the region. West African issues, for example, were significantly different to South African ones. The work plans must be prioritised according to these different situations, taking care to avoid duplication, but the overall project framework should be the same for all the case studies under the AfriCat umbrella.

The 'burning issues' identified by the workshop included:

- the need to clarify the organisational structure of the project, in particular the identification both of the key institutions that would act as a backbone and of the composition of the Policy Advisory Board (see below);
- the scarcity of data;
- a lack of background socio-economic data across the region;
- a concern over the adequacy of existing monitoring data, prompting a suggestion that remote sensing techniques might be applied to advantage, especially in assessments of, for example, the roles of land use change and deforestation;
- the general scarcity of flux measurements (water flows and sediment budgets) within the water continuum;
- the need for data-building and communication to be essential elements of the case study proposals so that ensuing policy can be based on high quality science with a robust database; and
- the need to develop a mechanism for relevant databanking and exchange, similar to that established for example in the IOC-RECOSCIX initiative for marine data.

The workshop affirmed the need for effective sub-regional co-ordination and a scientific co-ordinator for each study site, working under the general guidance of a Policy Advisory Board (PAB). The overall co-ordination of the further drafting process was dedicated to the Centre of African Wetlands, Ghana and the Pan-African START Secretariat (PASS). UNEP-ROA confirmed its support in generating the national, governmental approval for the initiative through the AMCEN process. The AfriCat secretariat should foster effective policy linkage by involving ministers with responsibilities for water resources, environment, tourism and development, as well as regional bodies such as SADC, river and coastal development authorities where these are established, and relevant NGOs.

Within the AfriBasins network the key contact persons identified for each of the case study sites (Table 3.1) agreed to assist in further developing specific research proposals and to investigate the options for potential funding on national and international levels. The workshop reiterated that, regardless of whether national or international financial support was targeted, the initiative and detailed networking requirements at site level would need to come from the regional scientific community. LOICZ could provide a framework and assist in sustaining the necessary links. AMCEN was identified as an appropriate platform to facilitate the governmental approval for the various site study plans in the broader context of the Abidjan Declaration.

3.4 Demonstration sites

In the selection of demonstration sites (Table 3.1) the workshop sought to provide coverage of key issues and representation of the sub-regional river-coast classes. Another aspect considered was the availability of data; an AfriCat work proposal should have a foundation in as much existing data as possible, although it was recognised that data availability and reliability will vary widely over the sites identified. The chosen catchments are mostly large, greater than 200,000 km^2, and extend over several countries thus involving a range of transboundary issues.

For the eastern side of the region, the inclusion of the Nile was confirmed, plus the Tana and Sabaki rivers as a linked site, the Rufiji, the Zambezi and the Incomati. For the Incomati site, the study could be built on earlier assessment and planning efforts conducted at the University Eduardo Mondlane and a draft trilateral project plan between Mozambique, South Africa and Swaziland, all of which were developed with support of the Coastal Management Centre of RIKZ in the Netherlands. A project on the integrated evaluation of riverine fluxes to the Maputo Bay region, "Catchment2Coast" recently funded by the European Commission, can be associated with the AfriCat project. This could be a key exercise in a continued second phase of the global LOICZ programme. For the western coast six sites were confirmed as providing suitable case study opportunities for AfriCat – the large catchments of the Congo, Cross, Niger, Volta and Senegal, and a group of small and medium catchments in Morocco.

Table 3.1 Demonstration sites for key case studies of catchment–coastal sea systems in Africa

Area/sub-regions: West coast	Major rivers	Regional characteristics and major coastal issues	Major drivers	Comments	Contact person(s)
1. North-west Africa	Moroccan catchments	• Semi-arid climate regime, small to medium catchments with high seasonal runoff variability • Nutrients and the ecosystem, coastal erosion/sedimentation, salinisation	Damming Agriculture	Good coverage of flux data within catchments, but few comprehensive studies on coastal linkage. Database to be generated Socio-economic profiles and analysis should be integrated and the results could be transposed to other north-west African catchments	M. Snoussi
2. West Africa	Senegal, Volta, Niger, Cross	• Transboundary catchments under strong and recent human influence • Coastal erosion • Changes in nutrient supply and habitats due to changes of material transports	Damming Deforestation	Fair cover of recent biogeochemical data Socio-economic information, sectoral statistics, I/O etc. expected to be rather limited; however, baseline project development undertaken in the Volta case (PDF-B status). Association with AfriCat and coverage of complementary issues is suggested.	I. Diop, A. Kane, G. Umoh, O. Martins, C. Gordon
3. Congo	Congo	• Nutrients	Uncontrolled urban growth	Apparently very limited	tba

Table 3.1 cont.

Nile					
5. Nile	Nile catchment and delta Alexandria city coast	• Transboundary river under extreme anthropogenic influence • Changes of material transports (sediments nutrients and water) to the floodplains and delta • Waste load	Agriculture in a narrow band along the catchment High population density Damming	Good coverage of biogeochemical and other scientific data. Socio-economic information, input-output tables = ? Opportunity to add integrative value to existing projects.	H. Awad
East Coast					
6. East Africa	Tana/Sabaki	• Visible coastal impacts from changed sediment loads and pollution	Damming, Agriculture	Comprehensive holistic study would partly have to generate database.	J. Kitheka, J. Ochiewo
	Rufiji	• Medium catchment in a monsoon-dominated climate • Delta discharges through mangrove forest to the largely pristine, richly biodiverse Mafia marine park	Potential damming Agriculture High population density	Data, particularly time series, generally very limited. Data generation would be necessary.	A. Ngusaru
1. Central/ southern Mozambique	Zambezi	• Large transboundary catchment with the largest reservoir in Africa • Erosion and changed material inputs	Damming	No comprehensive study available; investigations would partly have to generate data.	T. Forbes, L. Mhlanga
	Incomati	• Transboundary catchment with strong coastal signals of erosion and salinisation • Medium ranked eutrophication and biodiversity loss effects	Damming Agriculture Urbanisation	Reasonable coverage of biogeochemical and other scientific data. Earlier assessment and project development carried out with support from CMC-RIKZ – The Hague.	A. Hoguane, F. Tauacale
	Maputo Bay (including Incomati, Maputo and Umbeluzi rivers)	• Receives inflow from transboundary catchments with strong coastal signals of erosion and salinisation • Medium ranked eutrophication and biodiversity loss effects	Damming Agriculture Urbanisation	Project with potential for association to "AfriCat". Catchment2Coast – Integrated modelling of catchment -coastal resource interaction and management advice – EU funded.	P. Monteiro

3.5 Suggested "AfriCat" design

African Catchments – AfriCat
(Biogeochemical and Socio-Economic Dimensions of Catchment/Island-based loads to the Coastal Zones of Africa). This section gives a brief overview of the projected design of a comprehensive AfriCat umbrella project reflecting discussions during the AfriBasins assessment and synthesis process. The workshop adopted the design as a useful basis for an issue-driven project brief to be refined and developed by the regional scientists.

Introduction
Assessment and modelling of material transports to the coast considering river catchments and their associated coastal zone as one system should identify the loads to the coastal zone and determine which of the observed changes in the coastal zone can be attributed to human activities *versus* natural forcing. The actual impact observed/modelled depends on its biophysical properties. The regional system itself is subject not only to outside (long-term) pressures and drivers such as climate change but also to global socio-economic trends and changes. The integration of natural and social sciences required to address issues like critical concentrations and loads as well as resilience and carrying capacity uses the DPSIR framework, developed by the OECD and adapted.

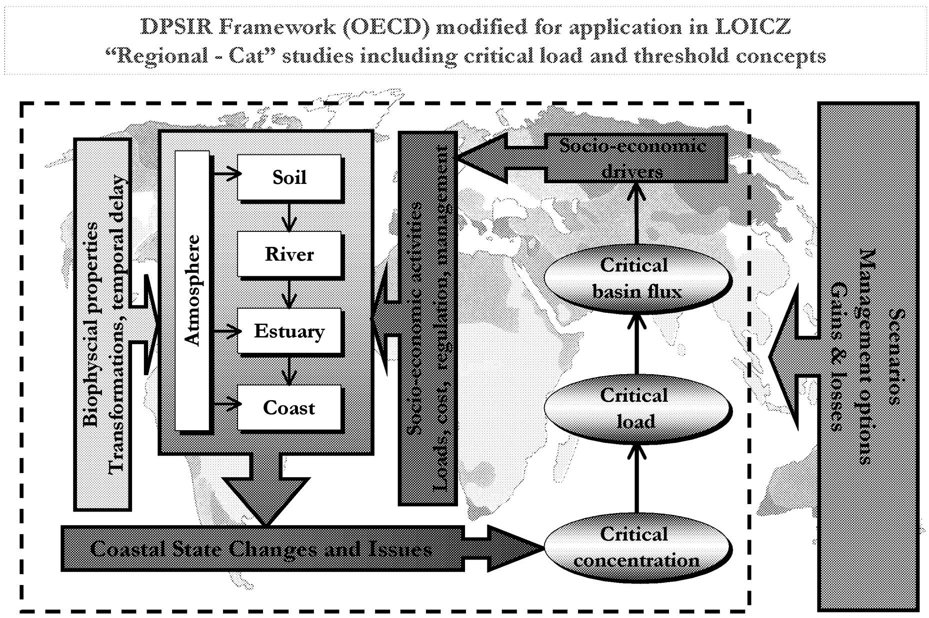


Figure 3.1 The DPSIR framework applied to the catchment – coastal sea continuum.

Structure
The AfriCat project is planned to cover between 6 and 10 regional catchments as study sites in Africa (see Table 3.1) exhibiting a range of characteristics with regard to coastal zone systems, habitats and their changes. They will be representative of a sub-region and the methodology applied aims to make intercomparison and up-scaling to broader African sub-regions possible. A set of sites may also be considered from the perspective of a common driver affecting catchment/coast systems e.g. damming thus enhancing the potential for comparison. Comparisons beyond the region will be possible through the global effort under the aegis of LOICZ.

To make the project manageable it is suggested to divide the effort into workpackages. Not all case studies will have all the necessary expertise available. Hence each workpackage will have a scientific co-ordinator with responsibility for contents and deliverables and will initiate (as necessary) capacity building across the sites and beyond. At case study level the site manager will take responsibility for the regional work packages. The workpackage co-ordinators and the site managers constitute the management team. Initial studies do not have to cover all the workpackages but will follow a common framework addressing the priority issues/drawbacks (e.g., dearth of data) of their site and implement the most critical workpackage in a first instance. Additional support will need to be generated later for a broader coverage of workpackages.

Workpackages - General Remarks

Significant parts of the assessment and synthesis will focus on improving understanding of how present activities in the catchment determine land-based fluxes and their impacts in the coastal zone. Emphasis will be on quantifying the type and scale of this relationship and elaborating on the implications for coastal resource use.

However, for the purposes of modelling and forecasting (Figure 3.2, right side), addressing the temporal scale of 'change' is also of scientific relevance. This is particularly important if the detrimental economic activities in the river catchments/islands causing coastal change are likely to continue.

Analysis will include information on previous fluxes where available. It is anticipated that the scarcity of even recent information will make primary data investigation necessary in several cases.

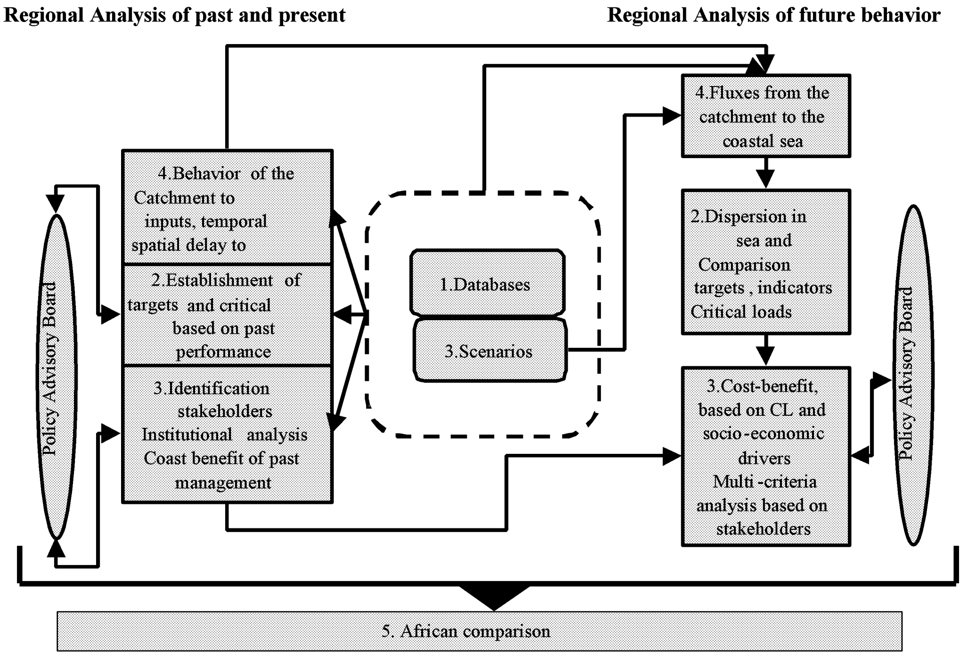


Figure 3.2 A potential "AfriCat" workplan.

The project database will include an inventory of land use in selected river catchments in Africa and an elucidation of their cause-effect relationships to coastal impact and state of coastal resources.

The 'human dimension' of fluxes to the coastal zone will be addressed as part of a study of comparative resource economics. The main objective will be to make a site-based macro-economic analysis of the impacts of the catchment economy on the coastal zone economy.

Finally, the proposed project will be concerned with management implications of the research findings, which will be communicated to the coastal user community through advisory boards. Scenarios representing various forcing conditions will provide information on biogeochemical changes and key questions in the realm of coastal management addressing issues such as:

- scaling of coastal change issues resulting from land-based fluxes and efforts for mitigation, i.e. specified land-use practices;
- technical and economic feasibility of modified land-use practices;
- economic instruments applicable for enforcement of improved changes in land use;

- types of public education and community participation needed to bring about appropriate changes (management response);
- institutional dimensions (national or river basin authorities) needed to formulate and achieve the desired changes.

Table 3.2. The workpackages in detail.

No	Description
1	Databases and tools
2	Impacts, indicators and critical loads
3	Scenarios and response/management options
4	Past, Present and Future changes in catchment fluxes
5	Integration at the African level

In WP 1 most of the effort will go into establishing databases for the catchments and coastal seas (monitoring data, geographical and socio-economic database). A geographical information system is the basis for the presentation of all of the spatial data and the results. This will draw on data and information provided through existing networks and other regional projects.

WP 2 will look at impacts in the coastal zone and derive indicators and critical thresholds for Africa (based on existing data and available models). Existing natural and social science models and tools will be combined to make an instrument suitable for carrying out the regional scenarios. With few exceptions there is only limited information on this topic now available.

WP 3 deals with the development of plausible scenarios of future change, based on available global scenarios but downscaled to Africa and then to the study sites and the sub-regions they represent. Socio-economic analysis of the scenarios and present functioning of the coastal zone can draw on experiences (as appropriate) and links to related LOICZ global activities. It is intended to adapt and use methodologies of the EuroCat (European Catchments) project such as the software package DEFINITE, to undertake both cost-benefit and multi-criteria analysis, the latter allowing the inclusion of costs and benefits which cannot be expressed in monetary terms.

To model catchment fluxes (WP 4) we will rely on models including point and diffuse sources as well as land cover. Tthe model MONERIS (Modelling Nutrient Emissions in River Systems) can be evaluated and adapted for African application.

In the second phase databases and modelling tools will be used to analyze past and present behaviour of the system. Trend data will be used to assess the past influence within the drainage basin of, for example land-use change, water regulation management, industrial development and population on fluxes. The temporal and spatial delay of the response of the coastal sea to these changes at the catchment level (regulations and socio-economic) will be evaluated and incorporated in the modelling tools. WP 5 will integrate the results of the individual studies.

A Policy Advisory Board (PAB) will be involved in stakeholder identification, institutional analysis and cost-benefit analysis of past measures. Dissemination of scientific findings to various target groups will be a key objective of the PAB.

Products
The project will provide a better understanding of the functioning and changes of African coastal systems under natural and human forcing. This will be based on an integrative coupling of biogeochemistry and socio-economic sciences combined with tools using a typological approach to upscale the findings to areas for which only secondary information is available *(*Maxwell and Buddemeier 2002*)*. Loads to the coastal zone and their critical thresholds for system functioning and thus the status and development of coastal resources will be addressed in the context of material transports along the whole water cascade as a single system. AfriCat aims to sets up a framework for analysis for coastal zone managers and will continue to

contribute on regional scales to the overall global LOICZ assessment and synthesis effort. Products will include:

- Catchment/Coast evaluation studies and peer-reviewed articles; (Study design will be based on the "EuroCat", adjusted to the regional needs, and will either have: a thematic approach, across the region e.g., driver-oriented across the region, or will select prominent differences between natural and anthropogenic change signals and combining them in one project or project cluster).
- Regional synthesis for evaluation in the global LOICZ network and the IGBP II integrated earth system science framework.
- Protocols for integrated assessment, modelling and forecasting for dissemination in training workshops;
- Issue-driven scientific decision support information put in a regional framework for broader application

The listing of information needs, data gaps and sites with negative trend expectations - "hot spots" - identified in the synthesis will form the basis for future proposal development. The synthesis will serve as the major regional focus 1/4 entry to the first global LOICZ synthesis and assessment book (to be published in early 2003). Proposals from this assessment process will seek links to regional initiatives. This will be promoted through LOICZ and support and close working relationships are likely with START, UNESCO's IOC and UNEP/ROA. The AfriCat process, in combination with LOICZ biogeochemical assessments of African estuaries and regional typology efforts (see LOICZ Newsletter 22, March 2002) will contribute to the implementation of the Abidjan and Nairobi Conventions (i.e. Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region, and Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region).

Earlier LOICZ-supported studies will provide a sound template for the regional approach for Africa. The AfriBasins network has started drafting proposals and various agencies have indicated their interest in funding the activities. Formal and/or operational links to ongoing international efforts such as the ICAM (Integrated Coastal Area Management) and GOOS (Global Ocean Observation System now COOP, Coastal Ocean Observation Panel) by UNESCO's IOC and regional UNEP and GPA activities will be pursued for global application and use of the outcomes.

4. CONTRIBUTED PAPERS

4.1 The impacts of human activities on Africa's coastal and marine areas and the implications for sustainable development

Eric O. Odada

Abstract
African nations are facing a growing number of coastal and marine changes as a result of development and increased population pressure. Unregulated human activities on land and the coastal changes can be viewed as taking place in a series of concentric circles - desertification in the center; deforestation towards the coasts; erosion and pollution on the coasts; over-exploitation of marine resources, dumping of toxic and hazardous wastes and oil spillage on the high seas.

There are a number of reasons for this serious situation, including is lack of awareness and understanding of coastal and marine resources and their interaction with terrestrial and oceanic processes, aggravated by ineffective coastal and marine planning and management.

The present status and trends of coastal and ocean development in the African region are examined, along with regional capabilities to implement sustainable development strategies.

Introduction

About 40% of the world's population lives within 60 km of the coast. In Africa, trends in population growth indicate that this figure could rise to 75% within the next century. The lives and reasonable aspirations for economic advancement of these coastal residents are inextricably linked to the productivity of coastal and marine resources. The shallow tropical coastal areas bordering the African continent have traditionally supported highly productive ecosystems from which fish and other aquatic resources have been harvested. These natural systems provide valuable services in terms of recreation, coastal tourism and marine transportation in addition to their natural protective and defense functions against coastal erosion and flooding. Unfortunately, most of the natural resources are over-exploited and the coastal and marine systems severely degraded by unregulated human activities. Productivity and usefulness of these coastal and marine areas have dramatically diminished and the prospects for sustainable development are greatly jeopardized.

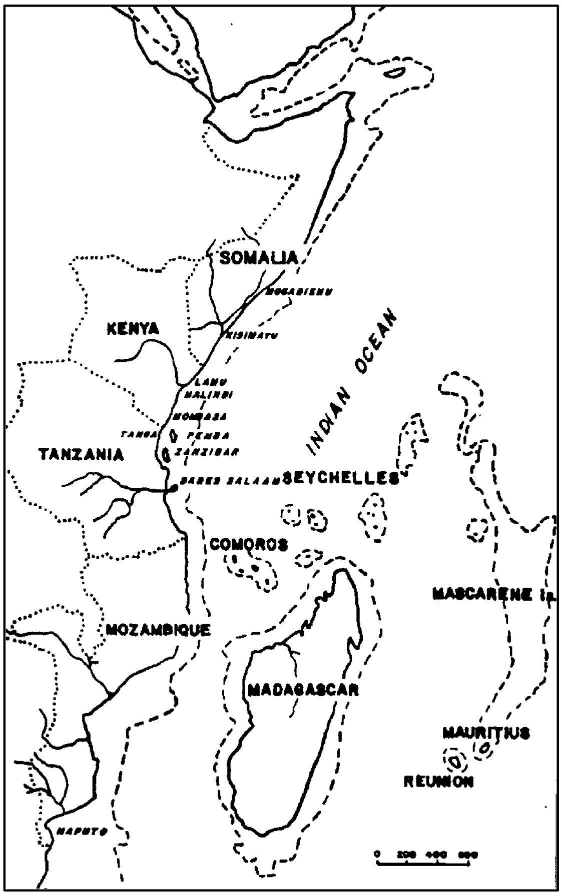
There is a general lack of awareness and understanding of the coastal and marine resources and their interaction with terrestrial and oceanic processes. Ineffective coastal planning and management further aggravates the situation. Despite the tenets of the 1992 United Nations Conference on the Environment and Development (UNCED), Chapter 17 of Agenda 21, that coastal states should "commit themselves to integrated management and sustainable development of coastal areas and the marine environment under their national jurisdiction", little has been achieved in the region.

North Africa

The coastal and marine areas in North Africa (Egypt, Libya, Algeria and Morocco) are generally regarded as developed, although less so than the northern coasts of the Mediterranean Sea. Agricultural run-off and rivers flowing into the Mediterranean Sea are responsible for substantial waste loads of organic and inorganic origin.

The biological productivity of the Mediterranean Sea is amongst the lowest in the world. Primary production in the centre of the Mediterranean Sea, and in many coastal areas away from the major rivers or urban agglomerations, is rather low, and nutrient concentration in the deep waters of the eastern basin are also very low. However, fishing activities in the Mediterranean Sea have been going on for centuries, adapting themselves to the local conditions to sustain a very high ratio of catch/production. Several factors may contribute to this high efficiency, among them, the distribution in time and space of the fertilizing mechanisms.

Eastern and Southern Africa



The coastal and marine areas of eastern Africa (Somalia, Kenya, Tanzania Mozambique) and southern Africa (South Africa and Namibia) (Figure 1) - contain some of the world's most extensive mangrove forests, vast stretches of seagrass beds, several hundreds of kilometres of sandy beaches, limestone cliffs, lagoons and rich coral reefs. These ecosystems support a wide diversity of plants and animals, and the derived economic benefits are essential for a large part of the population. These coastal and marine environments provide coastal population and inland communities with food, minerals, firewood and other vital resources.

Figure 1. The coast of East Africa. The dashed lines represents approximate limits of the continental shelves in the Western Indian Ocean.

West and Central Africa

The coastline of western and central Africa is about 8,000 km long and is characterized by marked diversity. The climate ranges from the Sahara Desert in the north through a humid tropical belt that contains two of Africa's largest rivers, the Niger and Congo, to desert again in the south - the Kalahari. The coastal zone shows equal diversity, ranging from dunes through marshy delta lands and mangroves to rias with steep cliffs. The continental shelf varies markedly in width from some 70 km or so in the Gulf of Guinea to about 4 km off Angola and Zaire (Figure 2). Even the countries that make up the sub-region differ markedly, from small island states such as Sao Tome and Principe to large mainland countries e.g., Nigeria and Mauritania. Their state of development also differs: some economies are based essentially on handicraft and subsistence farming, whereas others have developed industries.

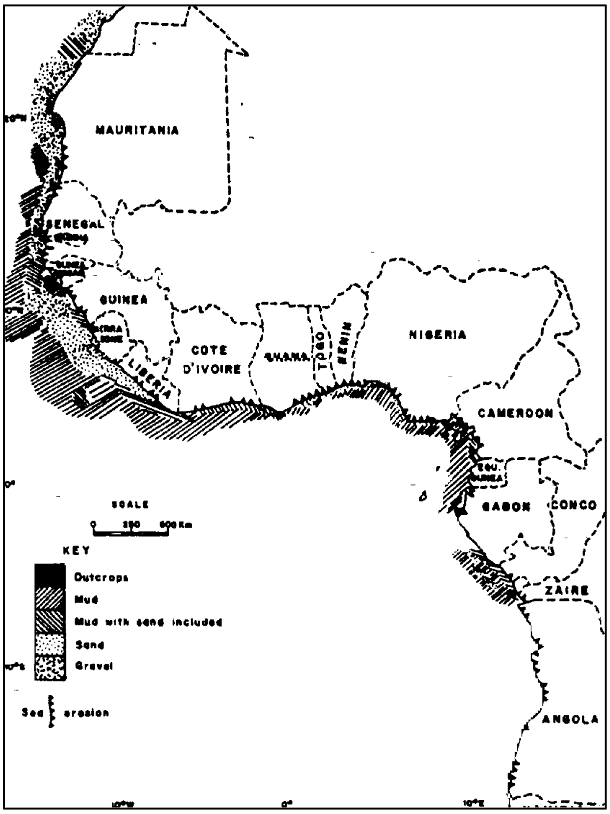


Figure 2. Coastal erosion problem sites along the West African coast (Ibe and Quelennec 1989).

Coastal and marine issues in Africa

Growing populations in coastal areas of the African region, expanding coastal tourism, intensified fisheries and a large number of other economic activities pose an increasing threat that jeopardizes the quality of these coastal environments. Large-scale destruction of coastal forests and mangroves, lagoons and coral reefs has caused serious degradation of the environment, affecting the lives of coastal inhabitants and economic development of the countries in the region. The Seychelles in the western Indian Ocean, for example, was famous for its luxuriant forests and abundant wildlife. Now, many reefs have been mined for coral, and mangrove forests on the granite islands have been razed or drained and reclaimed, causing severe erosion and smothering of coral reefs.

Rapid Population Growth
As the population of Africa increases, coastal and marine environments are assuming greater importance and need to be protected from pollution, coastal erosion and over-exploitation of marine resources through an integrated interdisciplinary and multi-sectoral approach in developing management plans for the coastal and marine areas of the region.

The total population of the countries in western and central Africa is estimated to be about 175 million, of whom about 10% live in the towns and villages of the coastal zone (UNEP 1984). Lagos, with >8 million people and 85% of Nigeria's industry, and Accra-Tema with 60% of Ghana's industry are good examples. In East Africa, about 84 million people live in the coastal zone. In Madagascar about 40% of the population lives along the coast. Substantial increases in the volume of sewage and effluent being discharged into the nearshore waters (mostly untreated) is a risk to human health through contact and consumption of contaminated seafood. This problem has received little attention in the region, despite sporadic outbreaks of human diseases attributed to contact with faecal remains on beaches (UNEP 1984).

Sea level rise
The Atlantic and Indian Ocean coasts of Africa are increasingly vulnerable to sea level rise and other impacts of climate change. The coastlines of eastern Africa, for example, have retreated inwards and seawards as a result of the rise and fall in sea level due to past climate change (Odada 1991). The Intergovernmental Panel on Climate Change (IPCC) has estimated an average rate of mean global sea level rise of about 6 cm per decade over the next century or as much as 1 m in 100 years. This would mean that vast areas of coastal wetlands and lowlands in the African region would be inundated, shorelines would retreat by hundreds of metres and protective structures would be breached. Flooding would threaten lives, agriculture, livestock, buildings and infrastructure. Salt water would advance landward into aquifers and up estuaries, threatening water supplies, ecosystems and agriculture.

Development of coastal areas
Development is leading to major changes in coastal areas of Africa, such as the construction of towns with associated industries and the creation or extension of ports and harbour areas, frequently close to areas suitable for tourism. At Lagos in Nigeria, Victoria Beach has been eroded 2 km inland since the construction of breakwaters (Ibe 1985). At the Port of Abidjan where the Canal de Vridi was opened in 1950 and a road has been cut through in the area, the beach has since eroded east of the canal.

Activities in the coastal zone often lead to the creation or rapid expansion of municipal centres on the coast without infrastructure and social services. In Malindi, Kenya, for example, tourism has increased rapidly in a traditional small municipal centre with extremely limited services and infrastructure. Population growth rates have reached 20% a year, and authorities are hard-pressed to meet basic needs for sanitation, education and commercial organisation. Similar situations arise wherever new coastal zone activities stimulate extremely rapid growth in new or small existing municipal centres. Economic planning is necessary for the sustainable development of coastal areas.

Coastal erosion and flooding
This is prevalent especially in West and Central Africa (Figure 2). The seriousness of the problem and the attempts to mitigate the nuisance and negative economic consequences vary. Retreat of the coastline, with concomitant flooding, causes hazards by removing settlements, destroying agricultural and recreational

lands, disrupting harbour and navigational structures and dislodging economic facilities located along coastal towns (Ibe and Quelennec 1989). Natural factors which facilitate erosion include storm wave regimes, orientation and nature of the coastline, low relief of the coastal plain, vulnerable sediment budget, narrowness of the continental shelf, presence of off-shore canyons and gullies, global eustatic rise in sea level. Man's intervention in the natural environment, by the construction of artificial structures on the coastline, mining of beach sand, the location of dams on rivers that normally would supply sediment replenishment to the coastline, the haphazard withdrawal of water from coastal aquifers and reservoirs and the destruction of mangroves, can exacerbate the impact of natural forces.

Environmental degradation

Coastal degradation is a major problem in the African region. The main sources of pollution from land are: domestic and commercial sewage and other discharges near coastal towns and cities; agricultural waste disposal; sand-mining in the coastal zone; erosion and siltation; overcutting of forests such as mangroves on the coastal strip and timber forests inland. Poor agricultural practice, lack of agricultural land especially on the islands, over-utilisation, burning, mismanagement and over-exploitation of forest resources have resulted in extensive deforestation and severe soil erosion. This has caused severe siltation with the resultant destruction of coral reefs, erosion of beaches and destruction of the coastal mangrove and other forests. Examples of this are clearly seen in Madagascar, the Comoros and many other parts of Africa.

Environmental values and natural resources factors have not always been integrated into development plans. Industrial expansion has often been carried out at the expense of the environment. Economic and social development, both urban and rural, has tended to deplete natural resources and damage the environment and amenities. Development of ports and harbours, reclamation for construction and dredging also cause coastal erosion and siltation. Such work has been common in the African region during the past two decades without due consideration given to the environmental impacts. Extensive dredging has been carried out in the Seychelles within the last decade leading to severe siltation of the coral reefs within the marine park and along the east coast of Mahé (UNEP 1984). In coastal areas of Tanzania, Mozambique, and Mauritius, dynamiting of coral reefs as a means of catching fish has resulted in serious environmental degradation of the coasts and seas. In Madagascar, the wide beaches that previously attracted many tourists to the island have disappeared. In spite of this, many structures are still being constructed on eroding beaches.

Oil pollution

Oil spillage due to accidents, grounding, harbour operations and discharges from refineries in the Eastern African sub-region can only increase as more and bigger tankers travel through the Indian Ocean. Some routes used by these tankers are shown in Figure 3. In 1981, 3551×10^6 tonnes of oil were transported through the main route from Arabian Sea to Asia. Accidents during tanker discharge operations in Mombasa, Maputo and Dar-es-Salaam have destroyed large areas of mangrove forests. Oil refineries in Eastern Africa significantly contribute to oil pollution of the coasts and seas.

West and Central Africa export oil to Europe and America. The coastline lies to the east and is downwind of the main route of oil transport from the Middle East to Europe (Figure 3). The total volume transported annually along the Gulf of Guinea, for example, has been estimated to be 706×10^6 tonnes (Portmann 1978) and the discharge of tank washings from offshore traffic is a significant source of oil on beaches. However, much of the oil found on beaches is from spills or tank washing discharges from tankers visiting ports in the region (Portmann *et al.* 1989). In the Ebrie Lagoon, Ivory Coast (Marchand and Martin 1985) a wide range of concentrations (1000-24000 mg/kg) of total hydrocarbons was found in lagoon sediments. The highest concentrations were associated with industrial and domestic sewage discharges. However, a spill of 400 tonnes of oil at a refinery in 1981 was still clearly detectable in 1983 (Portmann *et al.* 1989).

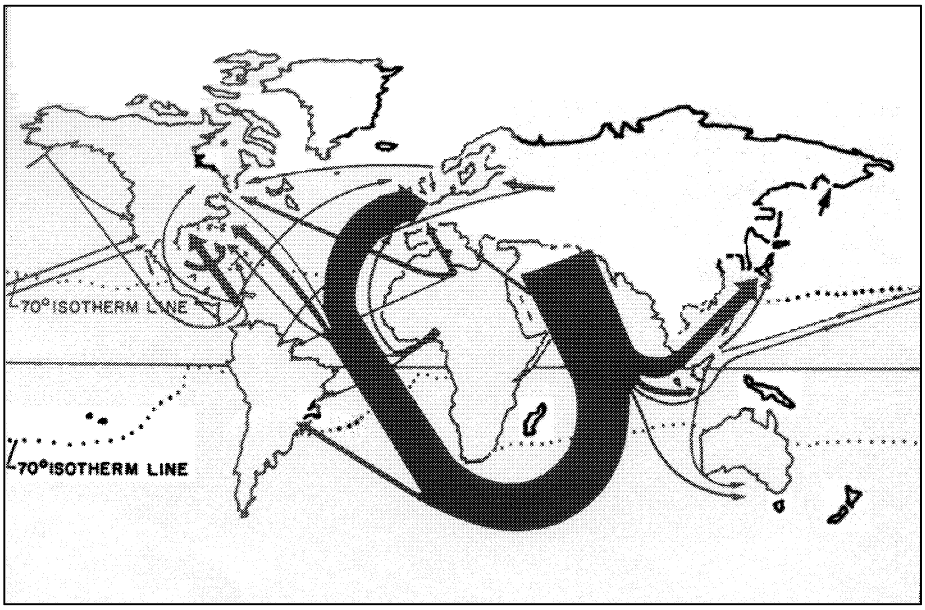


Figure 3. Main routes of oil transport from the Middle East to the Far East and the West around Africa (British Petroleum 1978).

Coastal tourism
The peoples of Africa have for a long time had visitors from Arab nations, Persia, Europe and other distant lands. The people are friendly and attractive with captivating life styles, customs and traditions, food preparation styles, costumes and distinctive artistic styles. In addition, the coastline of Africa is an area of great physical beauty, rich in living resources. In eastern Africa for example, palm-fringed beaches of white coral sand lead down to tranquil lagoons enclosed by spectacular coral reefs with their wealth of colourful fish, shell and corals. For many countries in the sub-region, coastal tourism is one of the most important sectors of their economies producing foreign exchange.

Although available evidence suggests that before the 1980s tourism in Africa occurred without significant deterioration in the coastal ecosystem, this is rapidly changing (Odada 1993).

Coastal agriculture
Agriculture is the mainstay of the economy of most African countries. Agriculture contributes between 30-60 % of their GNP and the majority of the population depends on it for their livelihood. While the population is increasing rapidly with the subsequent increase in food demand, in most African countries the land available for agriculture is shrinking because the land is used for non-agricultural purposes such as housing, industry, roads, playing fields or hotels, and also because good agricultural land is destroyed through soil erosion, salinization and modification.

Erosion related to deforestation and unwise agricultural practices is prevalent. In Kenya, silt from rivers is affecting catches of fish, smothering coral reefs and sullying beaches, with serious consequences for fishing and tourism. The effects of pesticide pollution on marine life are now becoming apparent in many countries of Africa. The health of humans is threatened by toxins contained in the fish they eat (UNEP 1989). Soil conservation measures and pesticide controls need to be instituted, particularly where agriculture is being developed.

Over-exploitation of marine resources
In general, the productivity of African coastal waters is dependent on the extent of the continental shelf, coastal upwellings, mangroves, coral reefs and runoff from rivers. Fisheries reflect the availability of these factors. For West and Central Africa, the total annual catch of fish in the coastal zone is estimated to be about $2.6x10^6$ tonnes per annum (FAO 1987) and about 10%of the coastal population engages in some form of fishing activity. At least 30% is canoe fishing, but larger fishing trawlers account for the bulk of the remaining catch (Portmann *et al.* 1989). Shrimp and tuna are the main commodities supporting export

ventures in eastern Africa. The extensive continental shelves of Madagascar and Mozambique support lucrative shrimp fisheries, while the absence of such areas in island countries make them dependent on offshore tuna resources.

The most serious problem in most African coastal and marine areas is over-exploitation of resources. Fish, shellfish, beche-de-mer, dugongs and turtles are all subject to over-exploitation on a massive scale, especially in East and West Africa, due to burgeoning human numbers coupled with a shortage of land-based jobs. Kenya's population of over 30 million, for example, is increasing at 4.3% annually, and is expected to double around 2020, with a consequent increase in demand for land, food, housing, water and social services. Similar situations in other parts of Africa are straining both terrestrial and marine ecosystems to breaking point.

Capacity for addressing coastal and marine issues

Institutions which will promote environmental and resource values and assure that they are taken into account in governmental decision-making are now being established in some countries of the region.

Environmental Policies
Most countries have no explicit policies relating to coastal and marine development. For the land-locked countries in the sub-region, coastal ports and harbours in other countries represent the only natural outlet for their imports and exports. The coastal states want to locate more industries on or near the coast to better utilise the main arteries of transport and communication.

Very little effort has been expended in incorporating socio-environmental concerns in development and problems discerned in the coastal areas have generally been shrugged off as being an inescapable part of the development process. Although serious environmental degradation of the marine environment has not yet occurred, disturbing and perhaps irreversible trends are beginning to appear, some in connection with activities outside the coastal zone.

Legislation and Environmental Law
Many countries have formulated regulatory measures for their resources management in coastal and marine areas, such as the issuance of permits for fishing, logging and mangrove harvesting. However, most of these measures have proven ineffective. Some countries are now enacting environmental laws which provide practical frameworks at the national level to implement environmental standards and to regulate activities. At the international level, conventions like the Law of the Sea, protocols and agreements such as the UNEP Regional Seas Programme provide a basis for co-operation among countries at bilateral, regional and global levels for the management of environmental risks, control of pollution and conservation of natural resources in coastal and marine areas. The groundwork has been carried out over the last two decades, under the aegis of UNEP, to establish a legal framework to manage regional seas.

Coastal Zone Management
A few countries are in the process of developing management plans for their coastal and marine areas.
In 1992 the Seychelles initiated a plan for coastal zone management under the UNEP Eastern African Regional Seas Plans, to prepare an inventory of coastal and marine species, the state of coral reefs, mangroves and lagoons, to assess the extent, nature and causes of coastal and marine pollution and to identify policy and remedial actions. The project components include training, institutional capacity building, workshops and provision of laboratory equipment. It is managed from the Department of Environment, created in June 1989 under the direct leadership of the President of the Seychelles to solve the environmental problems that stem from a general increase in the population and the rapid development of the island.

Tanzania is in the preliminary stages of the development of an integrated coastal zone management programme. In 1991 the country began the process of creating a protected area, to be known as the Mafia Island Marine Park (MIMP). This marine park will protect the last pristine coral reef ecosystem found in Tanzania's coastal waters – an area that is important as an economic resources upon which a significant coastal and island population group is quite dependent. The Tanzania government perceives that this project will serve as a pilot project for Tanzania's integrated coastal zone management.

Coastal and marine resources are valuable assets that can effectively contribute to sustainable development of the African region. However, uni-sectoral over-use of some resources has caused serious problems. Indiscriminate harvesting of mangroves brought short-term economic benefits to countries in East Africa, but was detrimental to fisheries, aquaculture and coastal tourism. Similarly, unregulated fishing efforts and the use of destructive fishing methods such as dynamiting have destroyed fish habitats and reduced fish stocks. There is an urgent need for integrated interdisciplinary and multi-sectoral approaches in developing management plans for the coastal and marine areas of the African region.

Institutional and administrative limitations
Most African coastal states are at present making only minimal use of their coastal and marine resources owing to limitations in scientific knowledge and technological know-how and to the lack of efficient organizational and administrative machinery. For example, shipping and navigation services, so vital for the management, control and exploitation of marine resources and for the development of international trade, are still very much in their infancy in most African coastal states. Marine technology is also very much underdeveloped in the region. Few countries have marine technology training centres with comprehensive programmes. The development of sound training and research programmes and effective linkages with the production system are basic but important steps towards enhancing the ability of African states to make full use of their coastal and marine resources.

Institutional and administrative capacities for coastal and marine resources development vary widely in the region, ranging from countries with a growing capacity and considerable resources to those with virtually no capabilities. Countries such as South Africa, Nigeria and Egypt already have good infrastructure for the development of coastal and marine areas, appropriate research and training institutions and other facilities, governments aware of the crucial role of coastal and marine resources in the development of their economies, and personnel qualified to undertake integrated management of coastal and marine areas.

Other countries, such as Benin, Gambia and Djibouti, are at a low stage of oceanographic development, with no substantial infrastructure for the development of coastal and marine resources, research and training institutions or other facilities, and shortages of trained manpower. Institutional and administrative capacity-building in ocean affairs should be a top priority in the African region.

Many African countries are confronted with serious manpower problems that are proving to be great impediments in the economic development of coastal and marine areas. In many cases, there is a lack of adequate training facilities for the type of manpower required. Although most African countries now have national universities and other institutions of higher learning, many of these institutions are young, and have problems with e.g., staffing, equipment and curriculum development. The universities are still grappling with the fundamental issues such as manpower for the civil service requiring high-level personnel, such as public administration, school education, public health and agriculture.

Other needs for manpower development, for example training of marine scientists and technologists are beyond the capability of most African states and need to be met through regional and sub-regional co-operation. Seminars, workshops and conferences such as those organised by the International Ocean Institute would be most useful and appropriate.

Measures for addressing issues of coastal and marine areas

As stated in Chapter 17 of Agenda 21 of the 1992 United Nations Conference on the Environment and Development (UNCED) in Brazil, coastal and marine management must play an important role if resources are to be exploited in a way that ensures sustainable development to a growing population. To implement sustainable development of coastal and marine areas of the region, African governments need to

(1) develop human resources by undertaking short-term and academic training to strengthen existing

capabilities;

(2) promote public awareness by producing educational materials on the ecological and socio-economic contributions of the coastal and marine resources and the consequences of unsustainable exploitation;
(3) organize policy workshops involving relevant policy and law makers to increase their understanding of and commitment to the sustainable use of the resources in their coastal and marine areas; and
(4) Implement integrated coastal zone management programmes by establishing case studies in pilot sites of coastal and island states in the African region.

Capacity building
Since the requirements for high level manpower in certain areas of marine sciences e.g., physical, chemical, biological oceanography, aquaculture, are not so great in terms of numbers needed by any one country at a time, existing institutions (e.g. universities) in the region suited for teaching and research could specialise as regional or sub-regional training centres.

Oceanographic research should be carried out on a regional or sub-regional co-operative basis using collectively-operated research vessels which are well-equipped and well-staffed for all types of oceanographic research and for the on-board training of marine scientific and technical staff. The co-ordination of research on a regional scale, the exchange and dissemination of research information and the storage of research data are important support activities.

Public awareness
African governments need to increase public awareness of the long-term ramifications of coastal development. At present the general public is unaware of problems associated with the development of coastal and marine areas. National campaigns are needed to improve public awareness of national and regional issues in the protection and development of coastal and marine resources of the region. Education in the principles of protection and development of marine resources should be part of the ordinary educational curriculum at all levels, and through seminars and courses offered to the general public.
The Western Indian Ocean Marine Science Association (WIOMSA)has been formed with the secretariat at the Institute of Marine Science in Zanzibar. Its aims are:

(1) to promote and advance the educational, scientific and technological development of all aspects of marine science in the region;
(2) to provide a forum for discussion and dissemination of information and organise meetings, seminars and workshops for the presentation of information, findings and experiences on all subjects related to marine sciences;
(3) to encourage the support of marine science research, and the development and educational activities by government agencies and private sector; and
(4) to collect and disseminate scientific, technical and other information on marine sciences.

Environmental Legislation
Environmental legislation is providing practical frameworks at national levels to implement environmental standards and to regulate activities in coastal and marine areas of the African region. At the international level conventions, protocols and agreements provide a basis for co-operation among countries at bilateral, regional and global levels for the management of development activities, and control of pollution and conservation of marine resources. However, African states urgently need to review and where necessary expand, update or strengthen national legislation and regulation pertaining to the protection and development of the coastal and marine areas. The enforcement of national regulations related to coastal and marine resources protection and development needs to be improved. There is an urgent need to expand the accession to and ratification of international conventions, such as the Law of the Sea, and institute mechanisms at national levels to ensure their application.

Management Planning
The value of coastal and marine areas as entities within the framework of national development planning is not always recognised in Africa and many countries lack the administrative and legislative basis for implementing such an approach. Industrial expansion such as construction of ports and harbours has often been carried out at the expense of the environment. Economic and social development, both in the coastal

cities and the coastal zone, has tended to deplete natural resources and damage the environment and amenities. To solve these problems, the countries of the African region need to develop an integrated interdisciplinary and multi-sectoral approach in their management plans for coastal and marine areas. Pilot coastal sites could be established in one or two countries in each sub-region, with intensive interdisciplinary involvement of resources and scientific personnel from universities, government agencies and non-governmental organisations. In addition, training courses, workshops and conferences should be organised, and publications and educational materials disseminated as part of the integrated coastal and marine resources management planning.

Summary and conclusion

The coastal and marine environments of the African region are uniquely situated to support a variety of activities and to serve diverse human needs for food, transport and recreation. However, the pressure of growing populations in coastal zones, expanded coastal tourism, intensified fisheries, and a large number of other economic activities pose an increasing threat which jeopardise the quality of these coastal and marine environments. The large-scale destruction of some of Africa's most valuable resources, the coastal forests and mangroves, the lagoons and coral reefs has caused serious degradation of the environment, affecting the life of the coastal inhabitants and the economic development of the countries of the region.

In the 1992 United Nations Conference on the Environment and Development (UNCED), protection of the coastal and marine environments to ensure sustainable use of natural resources was at the top of the agenda for action. Under Agenda 21, coastal states should "commit themselves to integrated management and sustainable development of coastal areas and marine environment under their national jurisdiction". The Conference further noted the importance of national policies and management capabilities for integrating the development and management of multi-sectoral activities in coastal and marine areas.

There are as yet no comprehensive study programmes covering the whole spectrum of marine science and technology.

To implement sustainable development of coastal and marine resources of the African region, there is an urgent need to: (1) build human resources by undertaking short-term and academic training to strengthen existing capabilities; (2) promote public awareness by producing educational materials on the ecological and socio-economic contributions of the marine resources and the consequences of unsustainable exploitation. (3) organize policy workshops, seminar and/or conferences involving relevant policy and law makers to increase their understanding of and commitment to the sustainable use of the resources in their coastal and marine areas, and (4) implement integrated coastal zone management programmes by establishing case studies in pilot sites in selected countries of the African region.

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4.2 The sub-Saharan African coastal zone: assessment of natural and human induced changes

Larry Awosika

Abstract

The coastal zone of sub-Saharan Africa stretches from Mauritania to Cape Town (South Africa) in the west and Cape Town to Somalia in the east, encompassing a total of 32 countries. The large marine ecosystems in these coastal regions consist of the Canary Current, Guinea, Benguela, Agulhas, Somali and Mascarene ecosystems. The African coastal zone consists of barrier/lagoon systems, wetlands, mangrove swamps, marshes, sloughs and estuaries that form major habitats for a wide variety of flora and fauna. The largest wetland in the region is the Niger Delta which is 1,794,000 ha consisting of 617,000 ha of saline and 1,177,000 ha of freshwater swampland. Other important wetlands include the Okovango Delta and the Kafue River flood plains. Most of the largest river catchment basins in Africa are found in West Africa. For example the Niger/Benue, Congo, Orange, Gambia are major rivers which form major catchment basins, draining the West African pre-Cambrian craton and the coastal areas. The population of Africa is approximately 650 million. According to the World Bank, Africa's coastal population will continue to grow at a rate of no less than 3% per year. With this growth rate, the population in the coastal urban area is expected to double within the next 30 years and by the year 2025, the urban coastal population will increase from a mean of 200 inhabitants/km^2 to 500 inhabitants/km^2. The high socio-economic activities within the coastal zone of the region stem from the fact that the coastal zone is blessed with a variety of resources which include fisheries and fauna resources, oil and gas, non-fuel minerals such as diamonds, sand and heavy minerals, natural habitats such as wetlands, mangroves, estuaries, coastal agricultural land, and recreational and scenic resources including beaches, coastal lagoons and estuaries.

Coastal areas of sub-Saharan Africa are presently experiencing coastal degradation in the form of coastal pollution, coastal erosion, siltation, flooding, deforestation, salt-water intrusion and subsidence. Many of these problems are caused or exacerbated by exploitation of coastal resources. Coastal erosion is the most prevalent coastal hazard in West and East Africa. Annual erosion rates of 25 to 30 m have been observed along the Victoria Beach in Lagos. Although natural causes like low coastal topography, high wave energy and the nature of sediments are responsible for these high rates of erosion, anthropogenic activities such as construction of harbour-protecting structures, jetties, beach sand-mining, construction of dams upstream and deforestation are mostly responsible for the high rates of erosion. Rapid growth of towns and industries in the region has contributed to the clearing of large areas of virgin forest. The net deforestation rate for tropical Africa is estimated at 3.6×10^6 ha/year representing about 0.67 of the total forest reserves of tropical Africa. Cutting down of mangroves for firewood and construction of houses has been blamed for the depletion of about 50% of the mangroves in Nigeria. The need to generate cheap and abundant electricity, water for irrigating dry land and development of inland fisheries led to the damming of many of the major rivers in the continent. Trapping of sediments behind the dams is depriving the coastal areas of sand. Such deprivation of sediments along the coastline is exacerbating coastal erosion and flooding. In some areas, excessive sediments are being generated as a result of anthropogenic activities. Excessive generation of sediments from upland areas also causes sedimentation downstream. The silting up of Korlee Lagoon in Ghana is a classic example. The Koba coastal rice field in Guinea is also suffering from excessive siltation by sediments generated from the upland areas. Oil exploration, exploitation and other related activities have led to frequent oil spills, deforestation, subsidence and subsequent pollution of the marine environment. Global climate change and associated impacts like sea-level rise and flooding have had serious impacts on the socio-economic activities in both the West and East African regions. The coastal nations of West and Central Africa (e.g. Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon and Angola) have low-lying lagoonal and erosive coasts and hence are likely to be threatened by sea-level rise. Environmental hazards facing sub-Saharan African coastal areas are great and need urgent and holistic approach. Although local and regional approaches may be necessary in some areas, many of the problems cut across international boundaries. A holistic approach to all environmental hazards calls for Integrated Coastal Area Management (ICAM) that will have a regional approach.

Introduction

Sub-Saharan Africa encompasses countries approximately south of the Sahara Desert to South Africa, including island states. This part of Africa is broken into two geographical regions: West and East Africa.

The West African coastal zone from Mauritania to Cape Town (South Africa) includes 22 countries: Mauritania, Gambia, Senegal, Cape Verde, Guinea Bissau, Guinea, Liberia, Sierra-Leone, Cote d'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon, Equatorial Guinea, Sao Tome and Principe, Congo, Zaire, Angola, Gabon, Namibia and the western part of South Africa (Figure 1).

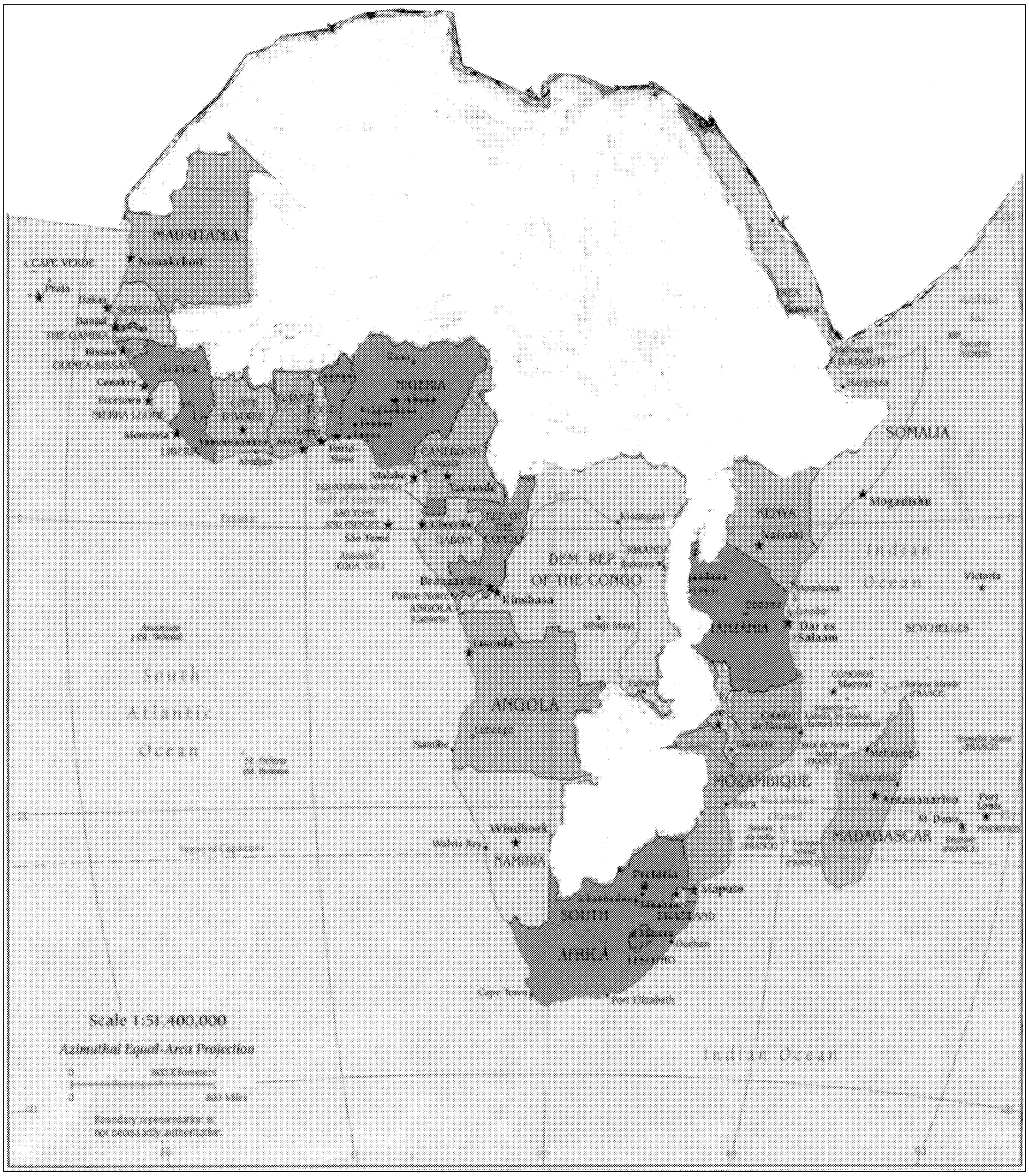

Figure 1. Coastal states of sub-Saharan Africa.

The East African sub Saharan countries include: South Africa, Mozambique, Tanzania, Kenya, Somalia, Madagascar, Comoros, Mauritius and Seychelles. The landward extent of the coastal zone in these regions is not well defined. However, the shelf break is regarded as the ocean seaward. The width of the shelf break varies from about 10 km to about 200 km. Table 1 shows coastal length and marine areas of sub-Saharan Africa. The large marine ecosystems in these coastal regions consist of the Canary Current, Guinea, Benguela, Agulhas, Somali and Mascarene ecosystems (Figure 2).

Coastal morphology

The major geomorphic features of the Eastern Atlantic Shelf in West Africa are bathymetric undulations consisting of sand shoals in the inner shelf, submarine canyons like Cayar Canyon in Senegal, Trou San Fonds in Côte d'Ivoire, Avon, Mahin and Calabar Canyons in Nigeria, and Congo Canyon in the Congo as well as other smaller gullies.

Table 1. Coastal length and marine area of sub-Saharan Africa states (compiled from World Resources 1994-95).

Country	Length of coastline (km)	Maritime area (x10^3 km^2)	
		Shelf width to 200 m depth	EEZ
Angola	1,600	66.9	605.7
Benin	121	7.0	27.1
Cameroon	402	10.6	15.4
Cape Verde	965	X	789.4
Congo	169	8.9	24.7
Côte d'Ivoire	515	10.3	104.8
Equatorial Guinea	296	X	283.2
Gabon	885	46.0	213.8
Gambia	80	X	19.5
Ghana	539	20.9	218.1
Guinea	346	38.4	71.0
Guinea Bissau	274	X	156.5
Liberia	579	19.6	229.7
Mauritania	754	44.3	154.3
Namibia	1,489	X	X
Nigeria	853	46.3	210.9
Sao Tome and Principe	215	X	X
Senegal	531	31.6	205.6
Sierra Leone	402	26.4	165.7
Togo	50	1.0	2.1
Zaire	37	1.0	1.0
Comoros	340	X	249
Kenya	536	14.4	118
Madagascar	4,828	180.4	1,292
Mauritius	117	91.6	1,183
Mozambique	2,470	104.3	562
Reunion*	201	X	X
Seychelles	491	50	1,349.3
Somalia	3,025	60.7	782.8
Tanzania	1,424	41.2	223.2
South Africa	2,881	143.3	1,553.4

X - No available data
* Reunion is geographically in Africa but politically part of France

Sedimentary fans, especially off the mouths of major rivers like the Niger Delta, dead Holocene coral banks (Allen and Wells 1962; Awosika 1990) and rocky bottom especially off Cape Three Points in Ghana, are other features of the shelf. A chain of narrow volcanic islands lies off Cameroon while the Guinea and Walvis (off Namibia) ridges emanating from the mid-Atlantic ridge constitute other sea-bed topographic and geomorphic highs in the shelf.

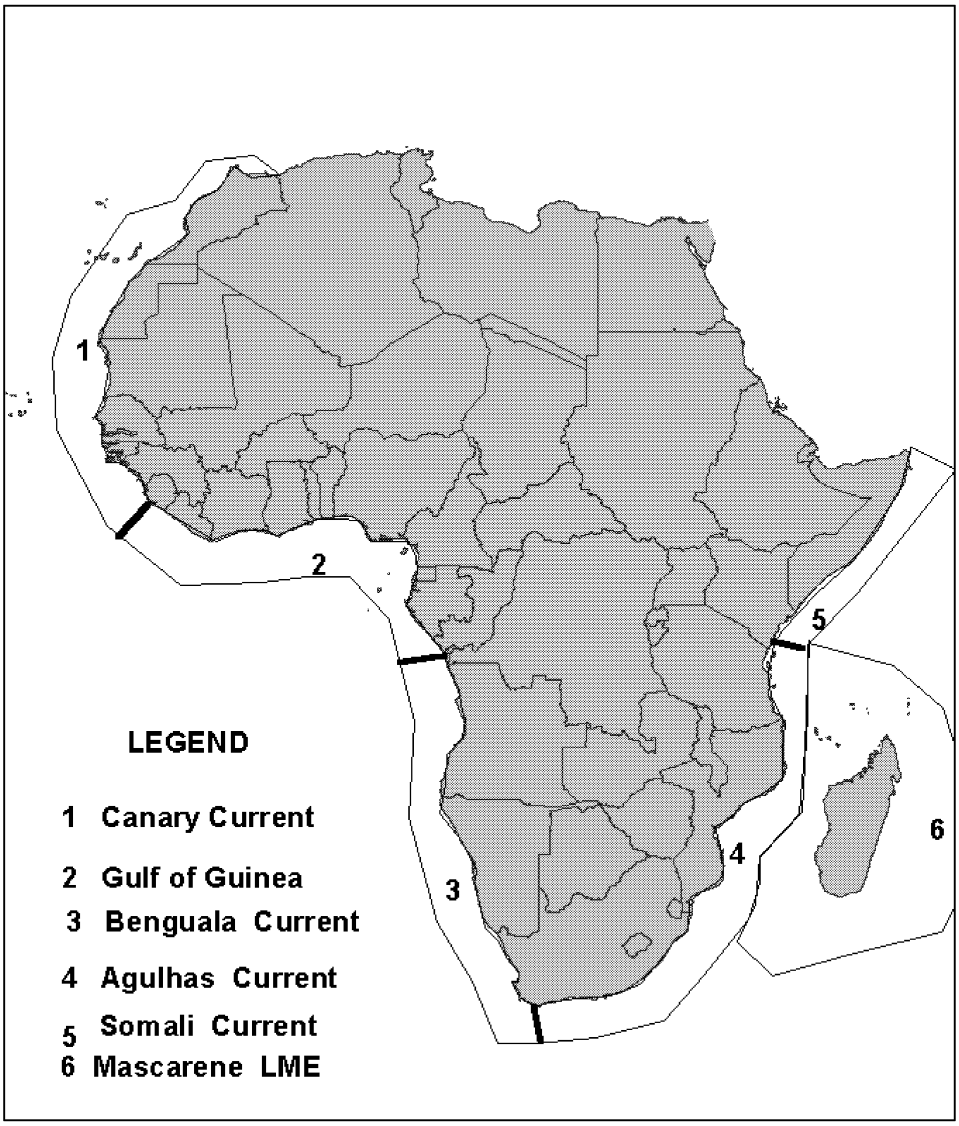

Figure 2. Large marine ecosystems of Africa.

Between Morocco and Senegal the coast is relatively unindented, while south-east of Monrovia the coast becomes indented with some offshore islands. Farther east, low-lying sandy deltaic/lagoonal ecosystems are very prominent. The coast between Monrovia and Cape Palmas in Ghana is interspersed with rocky headlands. Still farther east is the barrier-lagoon and deltaic coast between west of Abidjan and the Niger Delta. The Niger Delta is the largest delta in Africa with an area of 36,260 km^2 (Hughes and Hughes 1992). The Cameroon coast east of the Niger Delta is composed of rocky headlands interspersed with sandy low-lying coast with isolated lagoons.

The origin of the Seychelles Islands and other East African islands in the Western Indian Ocean can be traced back to the Cretaceous period when Madagascar and India were breaking away from Africa and drifting apart. The association of the Seychelles with Africa is confirmed by the existence of granitic rocks in most of the islands, which are of the same origin and date back to the pre-Cambrian era. However, the majority of the Seychelles islands are of limestone origin (fossil coral rock). Comoros and Mayote islands are believed to have appeared as a result of volcanic activity which occurred about 15 million years ago in the northern Mozambique Channel. Other islands which have a similar origin and originate from the same geologic period are Réunion, Mauritius, Rodriguez and Tromelin. The sporadic rocks bordering the continental margin of continental East Africa are mostly of Mesozoic origin (225 million years old). However, most of the coastal intertidal zone in Tanzania and Kenya is bordered by limestone cliffs and these have originated from coral reefs during the Pleistocene era (about 1.6 million years ago). The main cause of their formation is the long-term variation in sea level.

The western and northern coasts of Madagascar have a wide continental shelf. Comoros and Mauritius are surrounded by deep waters that begin at a few hundred metres to several kilometres offshore. There are some shallow banks around the Rodriguez Islands and other dependencies of Mauritius. The coral islands in the Seychelles are characterised by the absence of extensive shelves.

Major ecosystems on the East African coast include mangrove forests, both in estuaries and in non-estuarine areas, fringing coral reefs and patch reefs, sandy and rocky beaches, and extensive intertidal flats.

Socio-economic activities and developments

The sub-Saharan African coastal zone is the socio-economic nerve centre of the continent. The coastal region harbours the largest population density, industries and other commercial activities. The population of Africa is approximately 650 million (World Bank 1995b). According to the World Bank, Africa's coastal population will continue to grow at a rate of no less than 3% per year. With this growth rate the population in the coastal urban area is expected to double within the next 30 years and by the year 2025, urban coastal population will increase from a mean of 200 inhabitants/km^2 to 500 inhabitants/km^2.

In West Africa, a large percentage of the urban population lives in coastal cities (Table 2). In Nigeria, for example, about 20 million people (22.5% of the national population) live along the coastal zone while in Senegal about 4.5 million people (66.6% of the national population) live in the Dakar coastal area. In Guinea-Bissau 79% of the national population is concentrated in the coastal areas of the capital. Most capitals and industrial cities, e.g., Dakar, Abidjan, Accra, Lagos, Dar es Salaam and Maputo, are located in the coastal zone. In 1994, the combined population residing in the coastal zone of East Africa was estimated at 19 million, of which Kenya, Tanzania, Mozambique and Madagascar constituted 95%. It is estimated that 30% of South Africa's population live within 60 km of the coast. The population growth rates of mainland states of East Africa are generally high, ranging from 2.8% to 3.3%. However, the urban population growth rate is much higher than the observed national average ranging from 5.0% (Mombasa) to 7.2% (Maputo) per annum.

In some countries, marine resources form the main economic life wire of the GDP. For example, oil and gas are the main foreign exchange earners for Nigeria, Gabon and Angola, while coastal fisheries constitute a large percentage of the GDP of Ghana, Senegal, Cape Verde and Equatorial Guinea. Coastal tourism is also responsible for a large part of the economy of Gambia, Senegal, Côte d'Ivoire, Kenya, Tanzania, the Seychelles and South Africa.

Most of the industries are located in the coastal zone due to accessibility to the sea. About 60% of the industries in the Gulf of Guinea states are located within the coastal zone (UNDP/GEF 1993). About 27 oil refineries and associated oil-related industries are in the Gulf of Guinea region.

About 90% of the industries in Senegal are located within the Dakar coastal zone. In Ghana as well as Benin, Togo and Sierra-Leone most of the economic activities that form the backbone of the economy are located within the coastal zone. There are also many local-scale industries consisting of textiles, pharmaceutical and plastic industries dotting the coastal zone. The coastal areas also form the main import export centres and food supplies for the landlocked countries of Africa.

Resources

Sub-Saharan African coastal areas are blessed with a variety of both living and non-living resources, which include:

- fisheries and faunal resources;
- oil and gas, non-fuel minerals such as sand, heavy minerals;

- natural habitats such as wetlands, mangroves, estuaries;
- coastal agricultural land; and
- recreational and scenic resources including beaches, coastal lagoons and estuaries.

Table 2. Populations in the coastal zone in relation to country population and area (from Africa: A framework for ICZM 1996).

Country	Country pop. 1994 (millions)	Coastal pop. 1994 (millions	Coastal pop. as % of country pop.	Country area (km²)	Coastal area (km²)	Coastal area as % of country area
West Africa						
Angola	11.53	2.89	25.07%	1,245,828	95,410	7.66%
Benin	5.18	1.86	35.91%	116,266	7,248	6.23%
Cameroon	13.22	1.57	11.88%	465,425	29,378	6.31%
Cape Verde	0.41	0.41	100.00%	4,288	4,288	100.00%
Congo	2.32	0.35	15.09%	345,196	11,538	3.34%
Côte d'Ivoire	13.5	3.74	27.70%	322,770	32,843	10.18%
Eq. Guinea	0.39	0.21	53.85%	27,207	13,414	49.30%
Gabon	1.56	0.65	41.67%	261,764	53,060	20.27%
Gambia	0.94	0.5	53.19%	11,373	4,147	36.46%
Ghana	16.7	5.47	32.75%	239,312	27,644	11.55%
Guinea	6.24	1.35	21.63%	245,156	25,175	10.27%
Guinea-Bissau	1.09	0.87	79.82%	33,101	22,351	67.52%
Liberia	2.9	1.3	44.83%	96,826	31,477	32.51%
Mauritania	2.2	0.22	10.00%	1,041,970	39,291	3.77%
Namibia	1.55	0.04	2.58%	818,346	87,802	10.73%
Nigeria	97.23	19.29	19.84%	913,612	65,880	7.21%
Sao Tome & Principe	0.13	0.13	100.00%	856	856	100.00%
Senegal	8.12	4.37	53.82%	197,836	35,058	17.72%
Sierra Leone	4.55	2.15	47.25%	71,706	25,802	35.98%
Togo	4.05	1.37	33.83%	57,334	4,570	7.97%
East Africa						
Comoros	0.63	0.63	100.00%	2,030	2,030	100.00%
Kenya	25.84	1.66	6.42%	588,045	32,447	5.52%
Madagascar	13.05	4.8	36.78%	592,797	242,745	40.95%
Mauritius	1.1	1.1	100.00%	1,328	1,328	100.00%
Mozambique	16.6	5.62	33.86%	789,508	162,938	20.64%
Reunion	0.64	0.64	100.00%	2,036	2,036	100.00%
Seychelles	0.07	0.07	100.00%	210	210	100.00%
Somalia	9.65	3.79	1.88%	2,507,302	46,217	1.84%
Tanzania	28.39	4.61	16.24	942,654	57,225	6.07%
South Africa	40.72	12.4	30.45%	1,216,919	152,734	12.55%

Fishery resources

Fish is the most important source of dietary animal protein in Africa. FAO estimated (FAO 1996) the total fish harvest potential at about 7.8 million in salt water fisheries and 2.7 million in fresh water fisheries. The total salt-water fish harvested by countries of the region amounted to 3.9 million tones in 1994 (this figure excludes the production of foreign fleet that does not land in the region). Off the eastern coast of Africa catches represent less than 10% of the total regional harvest (foreign and domestic catches combined). The coastal and marine areas provide about 90% of the fish production in the majority of countries in the region. Fishing is one of the largest industries in the East African islands of the Seychelles, Mauritius, Madagascar and Comoro. A large part of this fishing industry is composed of artisanal fishermen. For example, artisanal fisheries in the Seychelles exported an estimated 367.13 tonnes of fish in 1994, representing approximately one-third of total export of fresh and frozen fish from the Seychelles. The South African commercial fishing industry is worth about USD 10.2 billion annually. Table 3 shows some fishery statistics of some countries in the region. Targeted fish species in the East Central Atlantic include herrings, sardines, red fish, and tuna and jack mullet.

Increased and uncontrolled fishing methods employing unethical harvesting methods are leading to a decline in fisheries. Fish catches in many African states have shown a systematic decline since 1974. The infection of coastal waterways by floating weeds has led to a decline in fishery activities due to clogged waterways, estuaries and lagoons, for example in Abidjan, Lakou Lagoon in Benin and Lagos Lagoon in Nigeria. Uncontrolled exploitation of the fisheries by foreign vessels is also leading to depletion of some fish stocks.

Table 3. Average annual marine fish catch and percentage change of coastal states in sub-Saharan Africa (World Resources 1998-99).

Country	Average 1993-95 (10^3 mT)	Percent change 1983-85
Angola	77.5	(1)
Benin	13.5	192
Cameroon	41.9	25
Cape Verde	11	248
Congo	17.5	8
Côte d'Ivoire	57.5	(22)
Equatorial Guinea	3.3	15
Gabon	240	28
Gambia	19.5	124
Ghana	299.6	34
Guinea	60.3	130
Guinea Bissau	5.3	75
Kenya	107.6	86
Liberia	3.8	(61)
Madagascar	85.1	180
Mauritania	86.6	(0)
Mauritius	19.0	74
Mozambique	24.8	(27)
Namibia	304.5	2,336
Nigeria	187	14
Senegal	329.7	41
Sierra Leone	47.1	34
Somalia	15.4	(3)
South Africa	552	(32)
Tanzania	243.4	68
Togo	8.7	(23)

Negative numbers are in parentheses

Oil and gas

Though oil and gas are found mainly in a few countries of the region, they constitute probably the most important coastal resource in the region (Table 4). Oil and gas form the main source of foreign exchange earner for Nigeria representing almost 90% of income for the country. In 1990, production of oil from the coastal zone averaged approximately 1,800,000 barrels per day. In the same year, the proven reserve base rose from an estimated 16.5 billion barrels to almost 18 billion barrels. In addition, the country has 85 TCF of proven gas reserves and a further 15 TCF of probable gas reserves. Other countries with oil and gas reserves include Cameroon with about 65 million metric tons of crude oil and 60 billion cubic metres of natural gas, Côte d' Ivoire with 15 billion cubic metres of crude oil and 60 million cubic metres of natural gas. Other countries in the region have intensified exploration for crude oil and natural gas in their coastal zone. As at 1984, Ghana has been able to strike a reserve estimated at about 1 million cubic metres of crude oil in the coastal zone.

The only gas deposits in East Africa are found on the Tanzanian coast. These deposits are found in Songo Songo and Mnazi Bay in southern Tanzania and steps for their exploitation are under way.

Non-fuel minerals
Although oil and gas form the most important mineral resources in the coastal zone, other non-fuel minerals like sand, heavy minerals (hematite, goethite illmenite, magnetite, and zircon), limestone, and diamond exist both on land and offshore. However, due to the lack of adequate technology, only sand is presently being exploited mainly for beach nourishment and construction. The nearshore environment and the lagoons have abundant sand usually mined for construction, block moulding and beach nourishment. In Nigeria for example, over $14x10^6$ m^3 of sand were dredged from offshore borrow pits between 1960 and 1990 to nourish the fast-eroding Victoria Beach. About $13x10^6$ m^3 of sand were dredged from the Lagos Lagoon between 1990 and 1991 to nourish the Lekki scheme development project area (Awosika and Dublin-Green, 1994).

Quarrying for sand and limestone occurs in all countries of the East Africa. For example, the annual demand for fine aggregates in Mauritius is $1.5x10^6$ tonnes and approximately 800,000 tonnes of sand are extracted from the lagoon areas. Sand mining in lagoons, beaches and coastal dunes is causing extensive beach erosion in the region. Titanium deposits are found in the estuarine areas of the Zambezi River and the coastal area north of Dar es Salaam.

Along the west coast of South Africa and in Namibia are rich diamond deposits. These diamond deposits were first discovered in 1908 by an ex-Kimberley labourer. By 1925, prospecting for diamonds covered the 80 km strip from Port Nolloth to the Orange River. The land-based diamond reserves are nearing depletion and decommissioning of the mines is being considered.

Table 4. Oil and gas reserves of some countries in sub-Sahara Africa (compiled from World Resources 1994-95).

Country	**Crude oil (1992) thousand tonnes**	**Natural gas (1992) million tonnes**
Benin	117	10
Cameroon	65	95
Cape Verde	0	0
Côte d' Ivoire	3	100
Equatorial Guinea	1	3
Gabon	190	11
Gambia	0	0
Ghana	0	0
Guinea	0	0
Guinea Bissau	0	0
Liberia	X	X
Madagascar	0	0
Mauritania	X	X
Mauritius	0	0
Mozambique	0	0
Nigeria	2,040	3,398
Senegal	136	0
Sierra Leone	0	0
Tanzania	0	28
Togo	X	X
Zaire	11	28

Freshwater resources: surface and groundwater
Most of the largest river catchment basins in Africa are found in West Africa. The coastal zone of eastern Africa is comparatively dry. Table 5 shows statistics of the 10 largest surface river bodies in the sub-Saharan African region. These rivers form major catchment basins which drain the African pre-Cambrian craton. These rivers cut across international boundaries and provide fresh water for millions of Africans along the banks and even beyond the riverbanks. This results in heavy pressures on surface water resources. Many of these rivers have also been dammed for hydroelectric generation as well as for irrigation. The groundwater resources of the coastal areas consist of unconfined aquifers with high water tables. This makes most of the water resources susceptible to saltwater intrusion and contamination from raw sewers and other pollutants.

Surface water supply is an important resource both for domestic and industrial uses. About two thirds of the urban population in coastal areas of Africa are without safe drinking water even though there are river networks and creeks, as well as abundant groundwater resources. By the year 2000 about 300 million Africans risk living in a water scarce environment, and by 2025, the number of countries experiencing water stress will rise to about 18, and more than 600 million people will be affected (World Bank 1995a).

Many of the rivers entering the Indian Ocean from continental East Africa have been dammed for generating electricity, irrigation and in some cases flood control. These projects have modified river flows and have led to increased surface water runoff, soil erosion, transportation of pollutants and aggravation of water shortage. The island states in both West and East Africa depend mostly on groundwater for both domestic and industrial uses due to lack of large, all-season-flowing rivers.

Table 5. The ten largest surface water bodies in sub-Saharan Africa with drainage areas more than 350,000 km^2 (Rangeley *et al.* 1994).

Basin	No. of countries	Basin area (1,000 km^2)	Basin countries
Congo	9	3,720	Zaire, Central African Republic, Angola, Congo, Zambia, Tanzania, Cameroon, Burundi, Rwanda, Sudan
Niger	9	2,220	Burkina Faso, Benin Côte d'Ivoire, Chad, Niger, Central African Republic, Nigeria, Sudan, Cameroon
Zambezi	8	1,420	Zambia, Angola, Zimbabwe, Mozambique, Malawi, Botswana, Tanzania, Namibia
Orange	4	950	South Africa, Namibia, Botswana, Lesotho
Okavango	4	529	Botswana, Angola, Namibia, Zimbabwe
Limpopo	4	385	South Africa, Botswana, Mozambique, Zimbabwe
Volta	6	379	Burkina Faso, Ghana, Togo, Côte d'Ivoire, Benin, Mali
Senegal	4	353	Mali, Mauritania, Senegal, Guinea

Major environmental changes

Coastal areas of sub-Saharan Africa are presently experiencing coastal degradation in the form of coastal erosion, siltation, flooding, pollution, deforestation, salt water intrusion and subsidence. Many of these problems are caused or exacerbated through exploitation of coastal resources. Major environmental changes are the result of the following:

- pollution;
- coastal erosion, flooding, siltation, deforestation;
- over-exploitation and degradation of marine resources; and
- deteriorating water quality and sanitation with impact on environment and public health.

All these coastal problems cut across national boundaries in both western and eastern Africa.

Pollution
The main sources of pollution in coastal areas are domestic wastes and industrial effluents. Most of the domestic wastes are solid wastes from coastal inhabitants. Much of this waste is not treated but is disposed

indiscriminately. Many large cities in sub-Sahara Africa lack centralised systems for collecting and treating domestic waste. Individual households use septic tanks, so the population generates more waste than industry. This results in pollution of groundwater. In Mombassa (Kenya), domestic sewage and storm water runoff account for 18% (4.566 t yr^{-1}) and 37% (12,802 t yr^{-1}) of the total BOD and suspended solids. The cities of Mogadishu (Somalia) and Majunga (Madagascar) have no centralised sewage systems, while those of Dar es Salaam (Tanzania), Maputo (Mozambique) and Mombasa (Kenya) can handle only 20% of the existing sewage load. The sewage systems do not have pre-treatment before they are discharged into the sea. For example in Port Louis (Mauritius) the sewage system serves 75% of the population but is dumped directly into the sea as raw sewage. This has led to sanitation and health problems in most metropolises in the Western Indian Ocean region. Maputo, the only city in the East African region with a central sewage system, is only able to treat about 50% of the sewage generated. The remaining 50% is emptied into rivers that flow into the Maputo Bay. This has led to an increase in the levels of total and faecal coliforms in Maputo Bay, making the bay area unsafe for tourism.

Because oil and gas industries are the most important economic activities in West Africa, oil spills and industrial affluence are the dominant sources of pollution in the region. In Nigeria, oil exploration, exploitation and disposal of raw sewers and industrial effluent have led to pollution of large areas of the coast especially in the Lagos area and the Niger Delta. Pollution of water, sediment and biota as a result of heavy metals and pesticides has been documented in the region (Portman *et al.*, 1989).

Domestic and industrial pollutants are generally associated with mega-cities like Lagos, Abidjan, Dakar and Port Harcourt (Table 6). About 70% of Nigeria's industries are located in the coastal zone and about 80% of the effluents and emissions are discharged without treatment. These industries consist of oil refineries, petrochemical, pharmaceuticals, textile, food and beverage and plastic industries. Mining operations produce large residues that are discharged into coastal waters, for example, large quantities of phosphate residues in Côte d'Ivoire and residues from diamond mining in Namibia. Oil tankers in coastal waters in the region, especially in oil-producing countries create an important pollution source through accidental oil spills and ballast discharge.

Since most of the industries in East Africa are agro-based, the wastes are organic and nutrient-rich and are commonly discharged to sewers or directly into the ocean or rivers. Msimbazi Creek in Dar es Salaam is heavily polluted by industrial effluents. Other areas of heavy pollution include Tudor and Kilindini Creeks in Mombassa, Mogadishu Harbour, the Matola River in Maputo and St. Louis in Mauritius. Oil pollution is significant in waters adjacent to oil refineries in Mombassa, Dar Es Salaam, Maputo and Tamatave.

Table 6. Domestic water and waste statistics of some coastal cities in Africa.

City – Country	Per capita water used/day	Wastewater treated %	Per capita solid waste generated %
Lunda – Angola	50	0	-
Porto Novo – Benin	22	-	0.5
Douala – Cameroon	33	5	0.7
Younde – Cameroon	61	20	0.8
Abidjan – Côte d'Ivoire	111	58	1.0
Libreville – Gabon	100	0	-
Banjul – The Gambia	106	0	0.3
Accra – Ghana	4	0	0.4
Conakry – Guinea	50	0	0.7
Antananarivo –Madagascar	40	0	0.3
Novakcht – Mauritania	35	10	0.9
Maputo – Mozambique	80	-	-
Lagos – Nigeria	80	-	1.1
Dakar – Senegal	64	69	4
Dar Es Salaam – Tanzania	50	2	1.0
Lomé – Togo	35	-	1.9

The ocean and beaches are used as dumping grounds for a variety of wastes from ships, tourists and even industries. Plastics are the most common debris on the beaches along the West African coast, most of which are brought in by tourists who litter the beaches with their left-over plastics and food containers. Table 7 shows the volume of debris collected in some African countries' international beach cleanup exercise in 1996. Results of the 1995 beach cleanup along Victoria Beach in Lagos (Table 8) revealed that plastics and foamed plastics constituted the most abundant debris category amounting to 31.86% of total pieces of debris collected. This was followed by paper and metal categories constituting 16.67% and 10.45% respectively. Rubber and glass categories constituted 7.36% and 6.88% respectively while cloth category amounted to only 4.06% of the total.

Table 7. 1996 international coastal clean-up results for selected countries in Africa.

Country	Debris Collected (pounds)	Debris collected (kg)	Length of beach cleaned (miles)	Length of beach cleaned (km)
Cameroon	16.328	7,422	1.2	0.7
Ivory Coast	5,005	2,275	1.4	0.9
Kenya	23`844	10,838	54.4	33.7
Nigeria	3,121	1,419	2.5	1.6
South Africa	9,005	4,093	33.5	20.8
Tanzania	8,360	3,800	0.3	0.1

Table 8. List of categories of debris collected during the 1995 beach clean-up at Victoria Beach, Lagos. Total weight of debris collected: 1,260.9kg.

Categories of debris	No. of pieces	% Composition of total
Plastics	6,768	31.86
foamed plastics	2,161	10.17
Glass	1,462	6.88
Rubbers	1,563	7.36
Metal	2,664	12.54
Paper	3,542	16.67
Wood	2,219	10.45
cloth pieces	862	4.06
TOTAL	**21,241**	**99.99**

Coastal erosion

Coastal erosion is the most prevalent coastal hazard in West and East Africa. Though natural causes like low coastal topography, high wave energy and nature of sediment are responsible for these high rates of erosion, anthropogenic activities such as construction of harbour protecting structures, jetties, beach sand mining, construction of dams upstream and deforestation are mostly responsible for the high rates of erosion. Typical areas of erosion include:

- **Senegal:** Niang (1990) reported annual erosion rates of 5.8 cm at Cape de Naze cliff, 32.9 cm at Cape des Biches and 29.3 cm at Fann Cliffs. For sandy coasts this rate is about 1 to 1.5 m per year.
- **Guinea:** Murdy and Sexton (1986) reported erosion phenomena in the northern part of the Camagenne Peninsula. Widespread erosion has also been reported along the Koba area especially at the mouth of the canals dug to drain excess water from the rice fields to the ocean.
- **Sierra Leone:** Collins *et al.* (1983) reported widespread erosion between Freetown and the eastern border especially off Sherbro Island.

- **Liberia:** Coastal erosion along the Liberian coast has been reported along cities like Buchaner, Greenville, Harper and Robertsport. Around the Organisation of African Unity (OAU) Beach, Shannon (1990) reported erosion rates of 3 m annually.
- **Côte d'Ivoire:** The La Vigie area with its coastal residential area of "Les Tourelles" and Adjoufun suffered extensive damage from erosion and flooding during the summer storms of 1984. Koffi *et al* (1990) reported coastal erosion rates of 1-2 m annually along the south-eastern coast (Fresco, Vridi, Port Bouet to Ghana border). High erosion rates have been reported in the areas off the Abidjan harbour.
- **Ghana:** Along Labadi Beach, an erosion rate of 3 m per year was reported between 1966 to 1975. At Ada near the Volta estuary erosion rates of 2.2 to 2.4 m annually have been reported between 1939 and 1976. Along the Keta coast, erosion rates of 4 m to 6 m per year between 1923 to 1975 have also been reported.
- **Togo:** East of the Lomé harbour an erosion rate of 20 m per year has been reported while the updrift western side has accreted so much that it is threatening to silt up the entrance to the Lomé port. The coastal road at Anneho has also been washed away as a result of the erosion.
- **Benin:** Erosion is very prevalent along Grand Popo, Seme and east of the Cotonou harbour. According to Adams (1990) erosion was sparked off with the construction of piers around the coastal areas of Kpeme factory, Aneho town, L. M. Hotel and Hotel da Silva. The New Town scheme, which was supposed to be a residential 'Hollywood' of Benin, has been devastated by erosion. Many of the roads, houses and other facilities constructed for the residents now lie under the sea.
- **Nigeria:** Erosion rates of 25 to 30 m annually have been documented along Victoria Beach in Lagos (Ibe *et al.* 1984). Although about six sand nourishment projects have been implemented on the beach since 1958, erosion continues to wash off large parts of the coast. Other areas where erosion has been very devastating along the Nigerian coast include Forcados 20 m per year, Brass 16-19 m per year, Eket 10-13 m per year and Awoye along the Mahin mud beach 20-30 m per year.
- **Kenya:** Coastal erosion is very prevalent along the cliffed beaches at Kanamai, Shanzu, Ivwetine, Nyali, Likoni, Black Cliff Point and Tiwi. High rates of erosion have also been reported along the sandy beaches north of Mtwapa Creek and north of Tudor creek at Bamburi-Kenyatta.
- **Mauritius:** Erosion has been reported along the coast of Cape Malheureux to Flic en Flac. Beach erosion rates of 10 m was reported along near the Le Morne Brabant Hotel in the past 15 years.
- **Tanzania:** Erosion is very prevalent along Kunduchi Beach north of Dar es Salaam. Hotels on tourist beaches like Hotel Africana, Kundichi Beach Hotel, Silver Sand Hotel, Rubgwe Oceanic Hotel and Bahari Hotel are threatened by beach erosion causing extensive damage. In Zanzibar, high erosion rates have threatened the coralline reefs in Ras Numgwi and the Maruhubi area in Zanzibar town.

Several activities in the hinterland have also caused adverse changes in the coastal zone. The need to generate cheap and abundant electricity, water for irrigating dry land and development of inland fisheries have led to the damming of many of the major rivers in the region. The construction of the Akosombo dam on the Volta in Ghana has led to a 60% reduction in the sediment load reaching the coastline (Collins *et al.* 1983). Several dams built on the River Niger in Nigeria have also led to a drastic reduction of sediments reaching the coastline. The Mono River in Togo with a pre-dam sediment discharge of about 21,000 cubic metres of sand now has a post-dam discharge of close to zero. Trapping of sediments behind the dams is depriving the coastal areas of sand. Such deprivation of sediments along the coastline is exacerbating coastal erosion and flooding. Excessive generation of sediments from upland areas also causes sedimentation downstream. The silting up of Korle Lagoon in Ghana is a classic example. The Koba coastal rice field in Guinea is also suffering from excessive siltation by sediments generated from the upland areas.

Land reclamation is extensive in the intertidal areas especially in the islands. In Victoria, Mahé, Seychelles, the airport, residential area and the port were built on reclaimed land. The extensive dunes in Mozambique are mined for construction materials causing significant beach erosion. Most of the rivers of the region have been dammed for water supply and irrigation. The damming of the Zambezi River (Mozambique) and Rufiji River (Tanzania) have resulted in significant adverse impacts on the ecological, and socio-economics at the Rufiji Delta.

Flooding
The low nature of the coastal zone makes the area susceptible to flooding especially during the rainy months of May to September. Storm surges are prevalent during April and August - September in West Africa (Awosika *et al.* 1995). These storms are usually associated with astronomical high tides exceeding 2 m above the normal high tide levels. These high waters result in flooding of the low-lying areas in the coastal zone. Poor drainage channels and clogged drainage channels with solid domestic wastes contribute immensely to flooding of coastal areas. The seasonal flooding of the Victoria Island during the rainy months and storm surges usually result in the dislocation of socio-economic activities of the economic nerve centre of Nigeria (Awosika *et al.* 1995). Seasonal flooding of the low-lying fringing coastal plains in East Africa is also prevalent.

Deforestation
Rapid urban growth and industries in the region have contributed to the clearing of large virgin forest. Table 9 shows the rate of deforestation in the region. A large part of coastal vegetation is composed of mangroves, palms, trees and scrubs. Large areas of the coastal forest areas are being destroyed to make room for industries, residential and commercial houses. The net deforestation rate for tropical Africa is estimated at 3.6m ha/year representing about 0.67% of total forest reserves of tropical Africa.

The coastal zone, though not densely forested due to its sandy nature, is known to have a variety of flora species. The fern, *Acrostichum aurem,* often grows among the mangroves. The grass, *Paspalum vaginatum,* a variety of which is used for mat-making is rapidly replacing virgin forest. The succulent herb, *Portulaca sp.,* is an important plant species in the coastal areas. Table 9 shows the forestry statistics for African coastal countries and rates of depletion. Between 1990 and 1995 African forest was depleted by about 3.5%.

Table 9. Forest areas, deforestation rate and loss of mangroves in selected sub-Sahara African countries.

Country	Closed forest (000 ha)	Deforestation rate (% per year)	Current extent of mangrove (000 ha)	Loss of mangroves (% of total)
Côte d'Ivoire	4,458	6.5	3	60
Nigeria	5,950	5.0	1052	50
Benin	47	2.6	7	x
Guinea-Bissau	660	2.6	315	70
Liberia	2,000	2.3	36	70
Guinea	2,050	1.8	120	60
Kenya	1,105	1.7	93	70
Madagascar	10,300	1.5	130	40
Angola	2,900	1.5	110	50
Ghana	1,718	1.3	2	70
Mozambique	935	1.1	276	60
Sierra Leone	740	0.8		50
Cameroon	17,920	0.4	486	40
Zaire	105,750	0.2	125	50
Gabon	20,500	0.1	115	50
Congo	21,340	0.1	2	0

Coastal vegetation in the region has been decimated by both natural and anthropogenic activities to the extent that a large percentage of the primeval vegetation has been replaced with new species. In Senegal for example, it is estimated that about 40% of the mangroves had been lost by 1980 (Table 9) and there are now extensive barren areas with acid-sulphate soils. As at 1980 about 60% of the mangroves in Guinea were reported to have been lost. In Liberia, nearly 70% of the mangrove vegetation had been lost as at 1980. In Ghana about 70% of the primary mangrove vegetation have been lost mainly through human activities. Most of the forest wood is used for fuel-wood. The original mangrove vegetation in these countries has now been replaced by the hardy grass *Paspalum vaginatum*. The once flourishing coconut and palm groves along many beaches have either been cut down or uprooted by erosion, leaving the beaches bare of vegetation.

Climate change and emerging coastal hazards

Global climate change and associated impacts such as sea-level rise and flooding have been documented to have serious impacts on socio-economic activities in the West African region. The coastal nations of West and Central Africa (e.g., Senegal, Gambia, Sierra Leone, Nigeria, Cameroon, Gabon and Angola) have low-lying lagoonal, erosive coasts, and hence are likely to be threatened by sea-level rise. Most countries in the coastal belt of the African region including Cape Verde, Sao Tome and Principe, Comoros, Mauritius, Reunion and Seychelles, where coastal areas represent 100% of the country (WRI 1994) would be affected by different IPCC (1995) scenarios of 0.5-1.0 m sea-level rise by the end of the 21st century.

Sea-level rise, combined with localised subsidence, is also expected to exacerbate coastal erosion and inundation in the region. Awosika *et al.* (1992) estimated that about 18,120-18,396 km^2 of Nigerian coastal areas could be at risk by the end of the twenty first century with a one meter sea-level rise (Table 10). This is expected to put about 3.18 million people at risk. Values at risk could amount to $18,134 million. Nicholls *et al.* (1993) also estimated that a one meter sea-level rise could put about 6,042 to 6,073 km^2 of the Senegalese coast at risk. This could again risk the lives of 109,000 to 178,000 coastal dwellers while risking values worth between $494 to $707 million. Productive wetlands and other ecosystems like the Niger Delta would be adversely affected by sea-level rise (Table 11). In Tanzania, sea-level scenarios of 0.5 and 1.0m sea-level rise per century will result in inundation of about 2,090 and 2,117 km^2 respectively. A one meter sea-level rise will lead to erosion of about 9 km^2 along the Tanzanian coastline (Mwaipopo 1997).

Table 10. Summary of Impacts and Response costs for a one meter sea level rise (after French and Awosika 1993).

	Senegal	**Nigeria**
Land at risk (km^2)	6,042 to 6,073	18,120 to 18,396
Population at risk	109,000 to 178,000	3,180,000
Value at risk *million)	US$494 to 707	US$18,134
Important area protection	US$255 to 845	US$558 to 688
Total protection	US$973 to 2,156	US$1,424 to 1,766

Table 11. Niger Delta (Nigeria) ASLR I and II physical effects and natural system projection to 21st century (from Awosika *et al.* 1995).

	Units	**Presently no ASLR**	**ASLR I**	**ASLR II**
1. Erosion rate	m/y	10 – 15	16-19 55-	20-25
2. Erosion-area lost **	km^2	26 - 45	120	130-330
3. Inundation and erosion**	km^2	3,000	7,000	15000
4. % of total area lost due to inundation and erosion	%	15%	35%	75%
5. Subsidence	*	*	*	*
6. Salinity				
(i) Salt wedge intrusion	*	*	*	*
(ii) Seepage rate	*	*	*	*
(iii) Seepage salinity	*	*	*	*
7. Natural System Responses (I) Agriculture (7,940 km^2)	km^2	794	2,779	5,955
8. No. of villages impacted	No	50	200	350
9. No. of people displaced	No	150,000	1-2m	2-3m

Conclusion
The economic loss due to degradation of the coastal areas will have serious consequences on the development of sub-Sahara Africa. It is estimated that decreased fishing has led to loss of income of many coastal states and local fishermen. Coastal erosion has led to destruction of buildings, tourist facilities, and valuable real estate. Changed hydrological regimes and inavailability of adequate fresh water has led to unsafe sanitary conditions and health problems leading to increase in medical bills. Sea-level rise and flooding would also have deleterious impacts on the economy of coastal States in the region.

On the socio-economic side, Africa's tourism industry could be adversely affected by the destruction of coastal infrastructure, sandy beaches, barrier bars and other marine ecosystems. Sea level rise adaptation or mitigating options will involve heavy costs, which the developing African states will find difficult to bear.

Environmental problems facing the sub-Saharan African areas are of high magnitude and need urgent and holistic approach. Although local and regional approaches may be necessary in some areas, many of the problems cut across international boundaries. In many places like Conakry Guinea, hard structures like sea walls have been constructed to control coastal erosion. Many of these structures have failed to solve the problem. Rather, they have resulted in the transfer of the problem down drift.

A holistic approach to all environmental problems calls for an Integrated Coastal Management (ICM) that will have a regional approach. In the drive by many governments to revamp their economy and provide social facilities there is a tendency to neglect sound and holistic environmental management plans. Many of the countries for example, Senegal, Côte d'Ivoire, Benin, Nigeria, Kenya, South Africa, Mauritius and Seychelles already have agencies or ministries of environment which have mandate for ensuring sustainable management of the environment. These governmental agencies have existing legislation with ingredients for effective management plans. However, these management plans are ineffective because of the following:

- lack of co-ordination and interactions between agencies with coastal zone mandates;
- lack of trained personnel and infrastructure for implementing ICM;
- inadequate data and information on coastal zone processes and activities; and
- Lack of adequate communication facilities for exchange of data and information.

Capacity (human and infrastructure) building is an essential element for effective implementation of ICM. Hence any regional ICM programme should include a well-articulated capacity building programme.

In conclusion a regional programme that takes onboard the following is urgently required:

- A regional database using geographic information system for analysis and evaluation of coastal indicators should be established in regional centres of excellence in the region. Data from such must be made accessible to planners and researchers as well as coastal zone stakeholders;

- tools for monitoring, assessment and decision-making must be standardised and made available to African countries, together with technical support;

- development of reliable regional climate change scenarios, impact assessments and policy development in the coastal zone and the entire marine environment will be needed; and

- Building capacity for coastal zone management through training, infrastructural development and upgrading population awareness will constitute important strategies.

A regional compilation of environmental problems, root causes and possible remedial options must be embarked upon. This process will identify “environmentally degraded hot spots” Identification of these ”hot spots” will ensure a clearer understanding of the problems and help in the implementation of sustainable remedial measures.

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4.3 Dissolved and particulate load of African rivers – an overview

O. Martins and W. Salomons

Abstract
This article gives a synthesis of available information and the extent of knowledge on the most important river basins in Africa. River discharge data covering between one year and almost forty years are considered in assessing the average water export to major world oceans by 50 rivers draining different geographic regions in the continent. Based on available information, chemical characteristic of surface river waters are summarized; sediment transport and mechanical erosion rate from the continent to the seas are also reviewed. The most important rivers in terms of discharge, are located in West and Central Africa with a total water export of 3700 km^3/yr and a combined sediment load of about 100 million tons/yr. Generally, the rivers are low in dissolved mineral content: dissolved silica and bicarbonate ions represent over 60% of dissolved species. Organic matter content of major rivers, as indicated by organic carbon and nitrogen loads in dissolved and particulate fractions, are evaluated, stressing the relative role of dams and reservoirs in all the rivers.

Key words Drainage basins - river discharges - water types - sediment load - organic - carbon - amino acids

Introduction

With an area of 30×10^6 km^2, the African continent ranks third among the earth's land masses. About 35% of the surface is drained by six rivers (Congo, Nile, Niger, Zambezi, Limpopo and Orange), and about as much as 10×10^6 km^2 of the surface is arid and desert area without surface drainages. In all, there are over 70 rivers on the continent whose drainage basins are greater than 10,000 km^2, located among over 40 countries (Figure 1).

Relative to other rivers of the world, very little is known about the flux of dissolved and particulate load of African rivers. The most recent information was catalogued under the auspices of a SCOPE project on mineral and carbon transport of major world rivers (Degens *et al.* 1991), where the emphasis was on a minimum 12-month sampling period of four of the largest drainage basins (Martins, 1983; 1988a and b; Kempe 1983; Nkounkou and Probst 1987; Hart 1985). Other studies carried out on smaller basins, the Senegal and Gambia Rivers, were published by Gac and Kane (1986a and b) and Lo (1984). More recently, Dupre *et al.* (1996) presented a study of major and trace elements of the Congo from a one-month cruise in 1989.

Dissolved and particulate fluxes of rivers are controlled by the nature and quantity of material within the basin, introduced into it by weathering, physico-chemical and biological processes operating on the rocks and within the aquatic medium at different rates and to varying degrees. These inputs and the controlling processes exhibit seasonal and inter-annual variations that are often difficult to comprehend because of the influences of the various factors. Thus, the amount of water transported by rivers is controlled mainly by dominant climatic type, while the lithology determines the chemical nature of the river water. River basins within the tropical rainforest belt therefore have high discharges, particularly where the basin is extensive (the Congo) and basins predominantly covered by sedimentary rocks have higher dissolved salt concentration than those of crystalline rocks. The effect of topography on the chemical composition of river water is closely linked to the frequently observed distribution of rocks, whereby sedimentary rocks are found mostly in mountainous areas, while crystalline rocks are widespread in lowland areas. Changes in land-use pattern, occasioned by man, influence the quality and quantity of river loads through:

- Discharge of domestic and agricultural wastes (organic matter, carbon, nitrogen and phosphorous compounds);
- Discharge of industrial wastes (trace metals, organic compounds);
- Urbanization, deforestation, canalization, dredging and mining, leading to enhanced mechanical erosion in the river basins and increased sediment load transport.
- Damming, and irrigation (water abstraction).

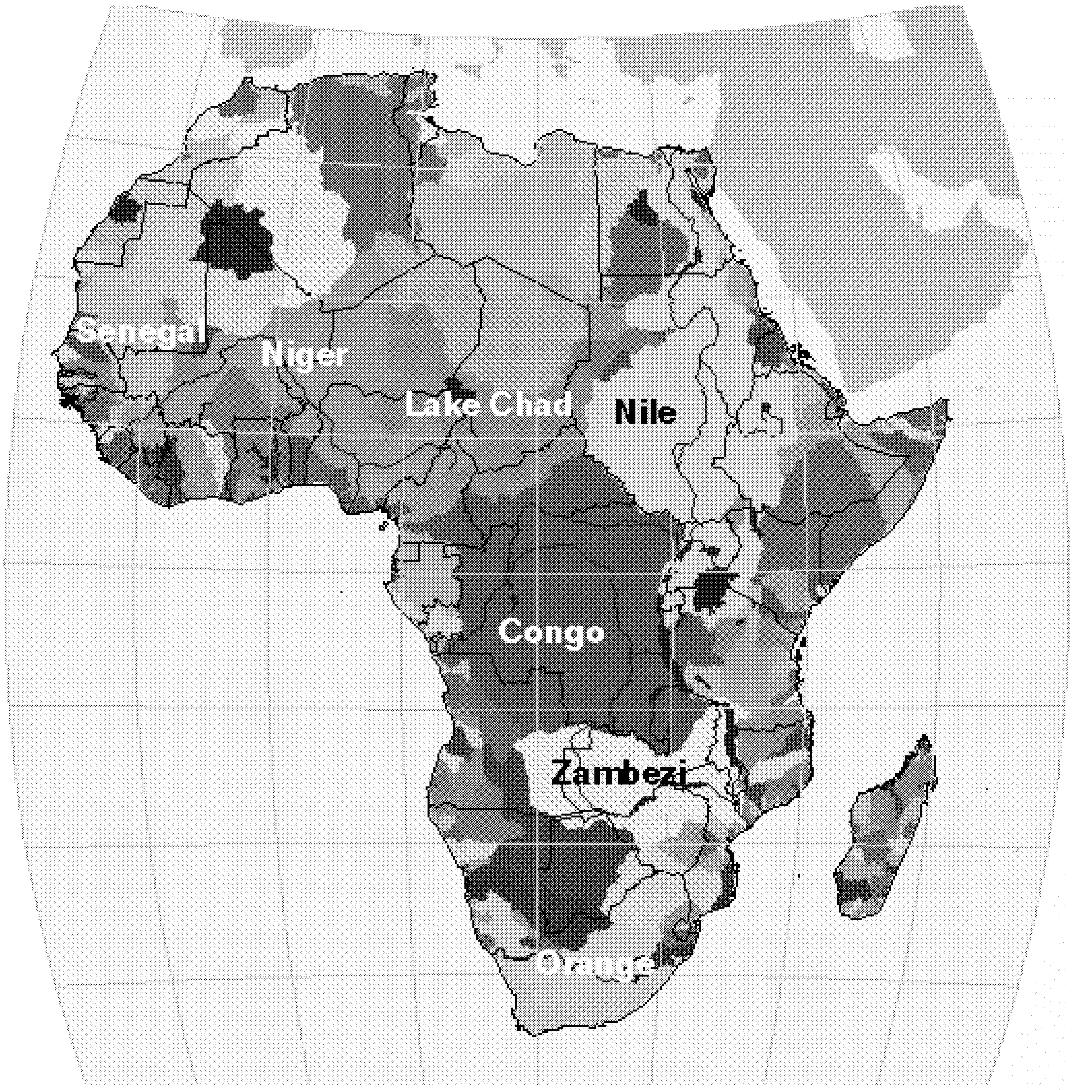

Figure 1. Africa's drainage basins superimposed on country political boundaries.
(from USGS 1996).

Table 1. Some hydro-climatic characteristics of major drainage basins in Africa.

River	Watershed area (10^6 km^2)	Mean Maximum elevation (m)	Major climatic type	Precipitation (mm yr^{-1})	Evapo-transpiration (mm yr^{-1})
Congo	3.7	1100	Tropical rainforest	1543	1150
Nile	3.0	1590	Arid	693	683
Niger	2.1	820	Semi-arid	558	423
Orange	0.95	1650	Semi-arid	419	408

Vegetation, geology and soils

Vegetation and soils are a direct derivative of the interplay between climate and rock types. Vegetation type reflects the soil potential: thus, desert soils are shallow and lacking in organic material, while areas with 250-600 mm yr^{-1} of rainfall have ferriginous soils which may be slightly acidic, if heavily leached. Due to the configuration of the drainage basins, a given vegetation belt may be found in two or more watersheds. Thus, tropical rainforest is found in the Niger delta and most of the Congo basin, while the tropical savannah zone covers most of the Niger basin, the south-east Congo basin, the Senegal and Gambia basins and the upper part of the Nile basin. Steppe and desert belts characterize the Nile and Orange drainage basins.

The lithologic outline is dominated by the Precambrian Basement Complex, consisting of granite gneisses, overlain by a thin layer of sedimentary rocks (<300 m thickness). Marine clays and coal-bearing continental deposits accumulated in southern and central Africa, while the northern sector is buried by clastic sediments (Continental Intercalaire), which include Nubian sandstone and various porous layers. In line with the relatively simple geology, the chemical composition of the dominant rocks (Table 2) is similar. Notable differences are in the SiO_2 content, where the Senegal and Gambia basins have higher percentages than the Niger, while the Niger shows more Al_2O_3 content.

Table 2. Average chemical composition (% oxides) of dominant rocks (Orange 1990).

Drainage Basin	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5
Senegal	86.0	5.0	2.0	1.4	1.0	1.5	0.82	0.53	0.29	0.03	0.05
Gambia	80.5	6.2	2.4	2.7	1.8	2.9	0.87	0.51	0.49	0.06	0.08
Niger	66.7	15.2	1.9	2.1	1.7	2.7	3.9	2.5	0.48	0.03	0.13

Methodology

Data sources

Most of the data presented were generated in the course of the SCOPE-sponsored project on carbon and mineral transport of major world rivers (Degens *et al.* 1991). Almost all river discharge data are extracted from the global river discharge database (Vörösmarty *et al.* 1996).

Laboratory analyses

Major ion analyses correspond to the recommended standard analytical methods using the AAS, while particulate matter was mostly collected by filtering 100 ml to 500 ml of homogenized water through pre-combusted and pre-weighed 25mm diameter Whatman GF/F filters clamped in a vertical filter tower, under reduced vacuum. Filters were dried and reweighed to determine the total suspended solids contents. The filtrate was collected and stored in conditioned PVC bottles and preserved with $HgCl_2$. Filters and filtrate were analyzed for organic components at the SCOPE/UNEP International Carbon Unit in the University of Hamburg. Details of the methods of analyses are described in Michaelis and Ittekkot (1982).

Results and discussion

Hydrology

Undisturbed flow in African rivers is characterized by seasonal and inter-annual variation; basins located in the northern hemisphere (Senegal, Gambia, Niger and Nile) have low flows between December and April, while the flood period in rivers from the southern hemisphere (Orange, Limpopo, Zambesi and Congo) occurs between March and June. The flow of most African rivers has been modified over the years by natural changes, such as frequent drought occurrences in the arid- and semi-arid-dominated basins and by changes in land-use pattern, such as large irrigation schemes and hydroelectric power plants through impoundments. The net effect is reduction in annual water volume reaching the adjoining seas.

Table 3. Station-specific river discharge data (Vörösmarty *et al.* 1996; Olofin and Martins 1993; Martins and Awokola 1996).

River	Country	Total drainage basin (km^2)	Station	Drainage area upstream (km^2)	Mean water volume (km^3 yr^{-1})	Years of data
Nile	Egypt	3.04x10^6	Asyut	3.0 x 10^6	38	1973-1984
Ouergha	Morocco		Ourtzagh	4 404	1.1	1951-1989
Bouregreg	Morocco		Lalla Chafia	3 230	0.08	1980-1984
Sebou	Morocco	38 402	Azib Soltane	17 250	1.2	1959-1989
Oum er Rebia	Morocco	34 000	Dechra el Oued	3 330	0.57	1953-1989
Moulouya	Morocco		Dar el Caid	24 422	0.37	1957-1988
Gambia	Senegal	70 000	Gouloumbu	42 000	4.6	1976-1979
Senegal	Senegal	437 000	Bakel	218 000	9.9	1904-1984
Cassamance	Senegal		Kolda	3 700	0.029	1967-1983
Moa	Sierra Leone	22 635	Moa-Bridge	17 150	19.0	1976-1977
Cestos	Liberia	15 011	Sawolo	683	0.8	1976-1983
Sehnkwehn	Liberia		Tounouta-Bafu Bay	761	3.5	1976-1978
Sassandra	I'Coast	68 000	Soubre	62 000	17.0	1979
Cavally	I'Coast	30 575	Tate	28 800	18.0	1979
Bandana	I'Coast	97 500	Tiassale	61 850	5.0	1979-1983
Tano	Ghana	15 975	Alenda	15 975	5.2	1965-1978
Pra	Ghana	24 588	Daboasi	22 714	4.2	1965-1978
Volta	Ghana	414 000	Senchi	394 100	27.6	1936-1979
Mono	Benin	23 430	Anthiem	21 575	2.0	1944-1984
Oueme	Benin	59 000	Bonou	46 990	1.4	1948-1984
Niger	Nigeria	2.12x10^6	Onitsha	2.1x10^6	127	1982-1986(*a*)
Ogun	Nigeria	22 000	Mokoloki	22 000	3	1978-1996(*b*)
Wouri	Cameroon		Yabassi	8 026	9.2	1951-1977
Nyong	Cameroon	26 480	Dehane	26 400	12.1	1951-1977
Cross	Cameroon	53 000	Mamfe	6 810	15.1	1967-1979
Sanaga	Cameroon	135 000	Edea	131 520	56	1943-1980
Nyanga	Gabon	24 704	Ibanga	20 000	17.3	1965-1974
Ngounie	Gabon		Fougamaou	22 000	22	1965-1974
Congo	Congo	3.7x10^6	Brazaville	3.5 x10^6	1 269	1971-1989
Kouilou	Congo	61 707	Sounda	55 010	26.6	1969-1982
Ogooue	Gabon	223 429	Lambarene	203 500	146	1930-1975
Ivindo	Gabon		Loa-Loa	48 500	23.8	1965-1974
Orange	South Africa	948 000	Vioolsdrif	0.850x10^6	5.9	1964-1986
Tugela	South Africa		Mandini	28 920	2.1	1964-1986
Grout-Vis	South Africa		Outspan	29 745	0.21	1969-1986
Maputo	Mozambique	31 272	Madubula	28 500	1.1	1976-1979
Zambezi	Mozambique	1.39x10^6	Matundo Cais	0.94x10^6	80	1976-1979
Save	Mozambique	107 293	Villafranca do Save	100 885	5.6	1976-1979
Limpopo	Mozambique	416 000	Chokwe	342 000	16.5	1976-1979
Buzi	Mozambique	27 865	Estaquinha	26 314	12	1976-1977
Imkomati	Mozambique	46 000	Chobela	37 600	3.3	1976-1979
Mangoky	Madagascar	60 263	Bevoay	53 225	21.2	1952-1983
Mananara	Madagascar		Maroangaty	14 160	7.3	1965-1978
Mandare	Madagascar	16 866	Amboassary	12 435	1.8	1951-1973
Tana	Kenya	671 000	Garissa	42 217	5.9	1934-1975
Ruvu	Tanzania		Morogoro Rd.	15 190	1.6	1959-1978
Rufiji	Tanzania	809 000	Stigeler's Gorge	158 200	22.6	1954-1978
Mbewe	Malawi		Chiromo	149 500	18.5	1953-1981
Shebelle	Somalia	0.339	Afgoi	278 000	1.6	1951-1979
Juba	Somalia	805 087	Lugh Ganana	179 520	5.7	1951-1979

Table 3 shows a list of important rivers, countries, discharge measuring stations, surface area of basin upstream of station and years of available data. The mean annual water volumes were calculated only for the last 10 years in most cases, as these have bearing on the most recent change in discharge to the estuaries. The most dramatic changes have occurred in the basins located in the arid and semi-arid regions (Nile, Niger and Orange rivers), influenced by climatic (drought) and damming impacts (increased evapo-transpiration as a result of water surface area increase). The case of the Nile has been well documented (Kempe 1983; Vörösmarty *et al.* 1996) The discharge of the Niger which was 220 km^3 in the pre-Kainji dam years, went down to 168 km^3 after the inception of the dam (Martins 1983). The water volume was further reduced to 127 km^3, as the Jebba dam started operation in 1985 (Olofin and Martins 1993). Similarly, the Orange River now has an annual water volume of less than 6 km^3 as against 11 km^3 (Hart 1985). Other rivers that may have been affected by reduction in discharge are the Volta and Zambezi rivers due to the large reservoir capacity (Table 4). Water loss and distortion of the natural hydrograph are some of the most important impacts of dams; the proportion of water lost is a factor of the lake surface area and climate. Thus, Lake Kariba (surface area=5200 km^2) loses 20% of its inflow to evapo-transpiration, while the Tiga dam in Nigeria with a surface area of only 180 km^2 losses up to 30% of its inflow by evapotranspiration due to the arid climate.

Inter-annual variations in river discharges are related to the rainfall pattern of the region. For instance, assessments of historical rainfall data for South Africa reveal that rainfall occurrences have been marked by a series of humid and dry years; an 18-year hydro-climatic cycle has been calculated for the southern Africa sector, as against observed 10-year cycle for the western part (Martins 1983). Inter-annual fluctuation amplitudes decrease from the semi-arid zone in direction of the equator. Thus, such hydro-climatic cycles are not pronounced in basins located in the equatorial rainforest zones .

Table 4. Africa's largest man-made lakes.

Name of reservoir	Completion date	River/ Country	Capacity ($x10^9$ m^3)
Aswan	1970	Nile/ Egypt	164
Kariba	1959	Zambezi/ Zimbabwe	185
Akosombo	1966	Volta/ Ghana	148
Cahora Bassa	1974	Zambezi/ Mozambique	64
Kainji	1968	Niger/ Nigeria	15
Le Roux	1976	Orange (Gariep)/ S. Africa	0.9

Dissolved minerals

Solute contents of rivers are naturally derived from three sources: atmospheric (anions and CO_2), lithologic (rock weathering) and groundwater infiltration (in artesian situations or dry season seepage). Chemical weathering of rocks remains the main source of dissolved substances, its rate being controlled by several factors among which topography, vegetation cover and humidity are primary. The solutes in African rivers are typically of the Ca, $NaHCO_3$ water type (Figure 2) and are therefore rock-dominated.

From a chemical reaction model, Martins (1988) showed that plagioclase, orthoclase and biotite breakdown accounts for 94% of the total dissolved solids (TDS) in the Niger, while Nkounkou and Probst (1987) concluded that only 24% of the bicarbonates are produced from weathered rocks; 76% of calcium, 69% of magnesium, 26% of sodium and 70% of potassium may have been derived from the chemical decomposition of parent rocks. All the rivers are generally low in TDS, mostly between 60–180 ppm, and they have relatively high $Si(OH)_4$, fluctuating between 7.0 and 25 ppm.

The seasonal variations in concentration follow a definite pattern in rivers with large floodplains, where an initial dilution of solutes precedes salinity increase as dissolved salts are leached from the floodplains into the main valley. The situation might be different in smaller rivers that dry up completely during 3 to 5 months of the hydrological cycle (Martins and Probst 1991). However, in view of the variability in river water volume, all fluxes of dissolved substances increase with discharge and in highly arid and semi-arid conditions, the flux variability can be very high (Meybeck 1996).

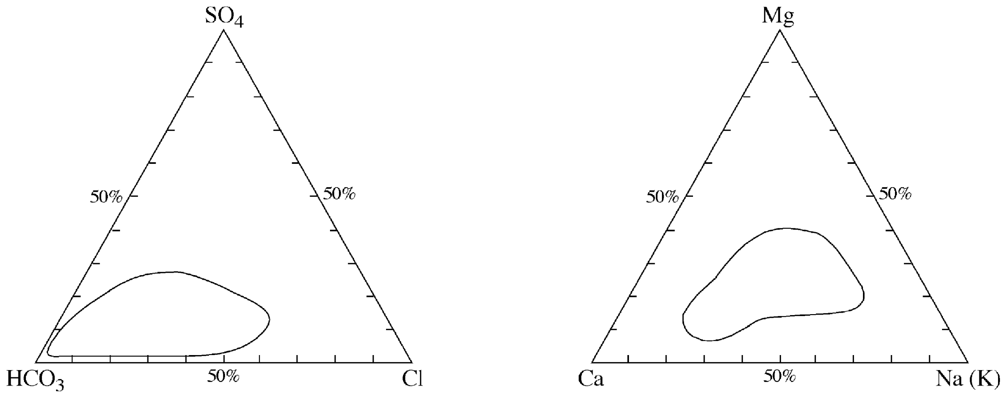

Figure 2. Trilinear plot of major ions in river surface waters

Nutrients
Data on the proportion of nutrients (C, N, P and Si) in African rivers is generally rare. Concentration of nitrogen and phosphorous compounds are generally low, while dissolved inorganic carbon and silica levels are appreciable. Table 5 shows some results on the nutrient content of the Orange River from the Verwoerd dam to the Le Roux dam. The nutrient concentrations are low, and show limited variation, possibly as a result of the impoundments. The proportion of dissolved inorganic carbon and silica are higher than 40% and 20%, respectively, of the total dissolved solids in most African rivers.

Table 5. Dissolved inorganic nitrogen (DIN), phosphate, total phosphorous, and total inorganic carbon (all values in ppm) in the Orange River (Hart 1985).

Sites	**DIN**	**PO_4-P**	**TOT-P**	**TIC**
Orange River (above Verwoerd dam)	0.37	0.07	0.42	13.2
Orange River (below Verwoerd dam)	0.74	0.09	0.11	14.7
Lake le Roux (at wall)	0.7	0.06	0.07	14.8
Orange River (below Le Roux dam)	0.7	0.07	0.08	14.9

Suspended sediments
The quality of suspended sediments is determined by geology and weathering type, while their quantity is controlled by topography, vegetation cover and river discharge. The total suspended sediment (TSS) concentration are very low in tropical rainforest rivers such as the Congo (< 40 ppm) and high in semi-arid rivers such as the Niger and Senegal rivers (127 and 196 ppm, respectively). The role of impoundments as sediment traps is evident from the drastic reduction of the concentration of TSS downstream of large dams. The TSS of the Nile before the closure of the Aswan dam was 3700 ppm, as against <1 ppm after the closure of the dam, thus showing a reservoir trapping efficiency of 100% (Milliman and Meade 1983; Vörösmarty *et al.* 1997). Reservoir operations such as in hydroelectric power generation, coupled with the low settling velocity of clay particles, may reduce the trapping efficiency of most dams. Rivers that receive highly discharging tributaries downstream of dams may still have high TSS concentrations when they reach the coastal areas.

The highest water and sediment discharges are exported from the west and central parts of the continent, in spite of the moderate rate of mechanical erosion. Most of the sediments from northern and southern Africa are stored behind dams, while wind erosion may be the predominant mode of sediment transportation in the northwestern and northeastern parts of the continent. East Africa and Madagascar have very high mechanical erosion rate due to altitude and moderate erosive power of the rivers.

Organic matter
Biogeochemical parameters such as organic carbon and organic nitrogen (dissolved and particulate), carbohydrates, amino acids and amino sugars give indication of biomass production within drainage basins. Organic matter content of rivers is controlled by the relative input from soils and from *in situ* primary productivity; the latter is labile and may be decomposed within the water column, while soil-derived organic matter is probably attached to humic materials and thus protected from such decomposition. Since there is significant fractionation, particularly of dissolved organic matter, taking place at the soil-river interface, the riverine organic matter profile may not necessarily reflect that of the soil. Tropical rainforest basins (e.g., the Congo) generate high DOC but remarkably low POC. The Orange and Gambia rivers have moderately higher DOC than POC, while the Niger and the Nile contain equal concentrations of both the dissolved and particulate forms of carbon. Mechanisms related to river geometry, residence times of organic matter in the water column and metabolic activities may also determine the concentration of organic matter of rivers. Some of the processes involved in the release of organic carbon are:

- Leaching of organic compounds from soils at high water stage.
- Accumulation of DOC on floodplains by leaching combined with heterotrophic decomposition of newly flooded terrestrial vegetation.
- Primary production and subsequent processing of fixed carbon in the water.

Since much of the nitrogen carried by rivers is in the form of proteinaceous materials, determinations of dissolved and particulate amino acids on acid hydrolysis should be expected to reveal the approximate quantity and nature of organic nitrogen transported (Ittekkot *et al.* 1983). Most of the rivers have dissolved amino acid in concentrations higher than 500 $\mu g\ l^{-1}$ and in most cases there are higher concentrations of the particulate fraction except in the Orange River. Amino sugars are also present in the samples from a few traces in the Congo and Orange rivers to about 60 $\mu g\ l^{-1}$ in the dissolved fraction, and from 5 $\mu g\ l^{-1}$ to 32 $\mu g\ l^{-1}$ in the particulate fraction.

The dominant amino acids are aspartic and glutamic acids, glycine and alanine in both dissolved and particulate fractions, while the relative amounts of these amino acids vary from one river to another. In the Orange and Niger, draining semi-arid areas, there is similarity in the distribution of particulate amino acids (PAA). In the dissolved phase, neutral amino acids such as serine and glycine dominate the samples collected from the Orange, whereas in the Niger neutral amino acids are dominated by glycine. Further, neutral and acidic amino acids show equal molar distribution patterns in the Niger. In the Nile, most of the isolated amino acids are in the particulate fraction, with the exception of valine, lycine and arginine. This is because most of the recycling of nitrogenous organic matter has probably occurred within Lake Nasser, so that the nitrogenous organic load of the Nile appears rather stable.

Conclusion

The state of relevant geo-scientific data of African rivers has not witnessed much improvement in the last 25 years. Our knowledge of river water quality has been enriched by two major projects – the SCOPE Project on transport of carbon and minerals in major world rivers and the GEMS-Water programme (jointly launched by UNEP, WHO, UNESCO, and WMO). Efforts to generate and collate data had been going on before these projects and are continuing, but in isolation and without standardization of sampling and analytical methodologies, making interpretation and comparison of results difficult, even on continental scale.

In general, river water quantity monitoring activities are more common and popular in most countries than river water quality measurements. Discharge/gauge monitoring stations are mostly limited to major rivers, dammed sections of rivers, or rivers used for navigation. However, there seems to be a lot of data gathered on individual country basis, by researchers in institutions of higher learning and research centers, but these data are difficult to access. Routine measurements of river water quantity and quality seem to be more common in the northern and southern African countries than in other parts of the continent. Data on major ion concentrations are more frequently found in the literatures than nutrient concentrations, while information on organic matter content of African rivers is generally lacking.

More scientists need to be exposed to continental and intercontinental meetings where recent data can be presented. The development of uniform sampling, monitoring and analytical tools that would enable good quality data acquisition and comparability of results, at least on a continental scale, is urgently required.

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4.4 Assessment and management program for the journey of pollutants through the River Nile to the Mediterranean Sea

Hassan Awad

Introduction

The River Nile has a large discharge area of about $3x10^6$ km^2 with a high flow rate (up to 500 m^3 s^{-1}). The flowing Nile River water reaches the Mediterranean Sea directly or indirectly through the drainage effluents network. These effluents are continuously pumped to the sea, carrying a complex of wastes. Quantities and quality of these wastes reflect the variability of human activities carried out in the countries bordering the Upper Nile basin (see Figure 1).

The dramatic deterioration in natural resources of the Egyptian coastal lakes and lagoons especially Manzala and Mariut lakes prove that the impact of pollutant discharges in the Upper Nile could reach the Mediterranean coast through these lagoons. The type, properties and persistence of discharged pollutants in Nile waters are determinant factors for their dispersal, residence and impacts in the receiving aquatic environments (fresh, brackish or saline).

Figure 1. The River Nile and countries bordering its basin.

Changes in the hydrology of the Nile since the construction of Aswan dam play a significant role on the fate of discharged pollutants in the river's environment. Comparison between the suspended and dissolved material contents in Nile water prior to and after construction of the dam showed that while the level of dissolved substances increased, suspended materials decreased. As a consequence, increases were noted in Nile water hardness, rate of alkali metal salts formation and their accumulation rate in the Nile's muddy bed. Meanwhile, the levels of bioavailable phosphate and silicate are decreased causing parallel reduction in water productivity.

On the other hand, although the infamous insecticide DDT has been banned from use in Egypt since 1970, there is evidence of that compound in the Mediterranean in detectable amounts in fish (El-Nabawi *et al.* 1987; Ernst *et al.* 1984), in water and in sediments (El-Gindy *et al.* 1991). In fact, almost all species of fish in Lake Nasser behind Aswan dam are contain high levels of DDT-type residues (160-470 ppb), especially following the spraying season of cotton in Sudan (Sebae 1994).

This paper evaluates the quantity and quality of discharged wastes from their point sources along the Nile River through Egypt and into the Mediterranean Sea via the coastal lagoons.

Industrial waste drainage

In 1991, a map was drawn by the Egyptian Environmental Affairs Agency (EEAA) in cooperation with the General Organization for Industrialization (GOFI) and Friedrich Ebert Foundation of Germany (FEF) for the purpose of assessing the impact of Egyptian industry on the River Nile. This map includes a detailed survey on the relationship between industrial potential and quantity and quality of produced wastes, water consumption and waste dispersal in the Nile. It was estimated that, from the identified principal 140 agglomerated point sources, 312 Mm^3 $yr^{-1}$of untreated industrial wastes are discharged directly into the Nile. The following conclusions were drawn:

- The public industrial sector in Egypt uses a total of 638 Mm^3 yr^{-1} of water, about 65% of which are supplied by Nile waters; 57% of the waste water produced (549 Mm^3 yr^{-1}) is discharged into the River Nile water systems (stream, branches, canals, drains and lakes).
- More than 60% of the industrial activity is concentrated in Cairo and Alexandria. These two regions are also responsible for the majority of the wastewater.
- The Alexandria region with its 85 large public factories and about 1700 private industrial units discharges 35 Mm^3 yr^{-1} of industrial wastes directly into the Mediterranean coastal waters through Lake Mariut. Other wastewater also reaches the Mediterranean coast via the Rosetta branch (13 Mm^3 yr^{-1}), canals (7 Mm^3 yr^{-1}) and sanitary systems (33 Mm^3 yr^{-1}). There is also more than 200 Mm^3 yr^{-1} of raw domestic wastes (EEAA 1992).
- Most of the food, spinning/weaving and chemical industries are concentrated in the Alexandria metropolis. Industrial drainage in this region is has high organic and organic chemical loads representing about 34% and 48% respectively of the overall waste produced from industry. It was estimated that 21%of soluble substances, 13% of oils and lubricants and 8% of heavy metals of the total overall industrial wasteload are discharged yearly from this region to coastal waters.

Agricultural waste drainage

About 80% of the Nile water budget in Egypt ($55.5x10^9$ m^3 yr^{-1}) is used for irrigation through the network of canals.

For a long time, Egypt was one of the major global consumers of agrochemicals because of the marked decrease in soil fertility due to the following two factors:

- The use of continuous irrigation in Egypt since the beginning of 19^{th} century had created a suitable environment for increasing numbers of plant and crop enemies (insects, fungi, weeds) in the continuously humid soils.
- Since the construction of Aswan dam in 1968 the passage of highly fertile Nile mud to the Egyptian fields has been hindered.

The usage rate of agrochemicals has increased in parallel with the continual decrease of soil fertility.

River Nile-Mediterranean Sea connections in Egypt

The Nile delta is almost situated in the middle of the 995 km-long Egyptian Mediterranean coast (15.8% of the total Mediterranean coast length). It joins the Mediterranean Sea through its two branches surrounding the delta at Domietta in the east and at Rosetta in the west. The river is also connected to the sea indirectly through four coastal lakes, namely Manzala, Burullus, Mariut and Edku lakes. These lakes, especially Manzala and Mariut, could be considered as transitional sinks for the majority of Egypt's anthropogenic wastes. The budget of the pollutant cocktail in the lakes is expected to be exposed to significant alteration in quantity and quality before reaching the Mediterranean Sea.

Since the construction of the Aswan dam in 1968, the historically positive biological effects of the huge quantities of fertile Nile water (40-50 $km^3\ yr^{-1}$) on the receiving Mediterranean coastal waters have become negative impacts. This impact is obvious in the decrease in nutrients in Nile waters (2.5-4 $km^3\ yr^{-1}$), water productivity and in fisheries (UNEP 1990). There has also been rapid development in industrial activity, agrochemical usage and population size. These factors make the Nile water reaching the Mediterranean Sea rich in all sorts of anthropogenic pollutants. Moreover, the decrease in natural settable suspended matters makes the journey of dissolved and minute solid wastes longer. However, the probability of reaching the Mediterranean coast has increased.

The coastal lagoons, which almost separate the Nile drainage area from the Mediterranean Sea, possibly play a significant role in limiting and modifying the pollutant levels in Nile water reaching the sea. In fact, these lagoons could be considered as the ultimate sinks for the major part of wastes in Nile water.

To estimate the overall impact of Nile water discharges in adding more of its constituents into the Mediterranean coastal waters, recent data were analysed. The data included the range of variation in concentrations of salinity (as chlorosity), dissolved organic matter (DOM) and nutrient salts (nitrate, nitrite, phosphate and silicate) in waters of the two main Nile branches (Damietta and Rosetta) and in the four coastal lagoons. From these data, the total annual inputs for each of the considered constituents into the Mediterranean receiving waters were estimated at different outlets. In general, the results indicate the significant contribution of discharged Nile water on the coastal water quality of the Egyptian Mediterranean environment especially in front of the Nile Delta (Awad and Hassan 1998).

Deterioration of the nearby marine environment in some areas, especially off the Alexandria metropolis, is a result of direct discharge of industrial pollutants and untreated domestic wastes into the coastal waters. The same conditions are dominant in the coastal zone off Lake Manzala. In fact the zone of the Mediterranean coastal waters off Alexandria is considered to be one of the hottest "hot spots" in the region (UNEP/MAP 1997).

Taking into account the above information (for more details see GOIF/FEF/EEAA 1991; EEAA 1992; SAAD 1997), the need for a monitoring mechanism near the River Nile mouth was recognised.

This mechanism, which could be either a permanent "Observatory" or a Monitoring and Enforcement Coordination Unit (MECU) is an urgent need, but will also be a useful tool for making decisions not only for the Alexandria metropolis but for the whole country and will benefit of the whole Mediterranean basin. It will serve as a data-bank for the dispersed environmental data and can overcome the current problem of lack of coordination and cooperation among the environmental authorities and institutions in Egypt.

The implementation of the proposed Nile-Mediterranean Observatory as MECU will be a practical tool for the success of the planned regional programmes aimed to develop local community capacities around the Mediterranean basin and to enforce the national and regional legislation. Indeed, the implementation of such a mechanism in association with other partners in the region will strengthen the cooperation between Mediterranean communities to protect, sustain, conserve and develop their irreplaceable natural heritage and environmental resources in at least a part of the Mediterranean basin.

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4.5 Impact of dam construction on the sedimentary budget of the Sebou River (Morocco) and its estuarine zone

Souad Haida, Jean Luc Probst and Maria Snoussi

Abstract

A study on water and suspended sediment discharges exported by the Sebou River after dam construction shows the effects of the dams on the river downstream and on the estuary. The construction of large dams, supplemented by climatic fluctuations, has led to a sharp reduction of water inflow and sediment discharge. A maximum amount of sediment trapping (85-95% of the sediment load) occurred in the lakes of the reservoirs, which have a short useful life (42 to 910 years). Grain size studies have shown the extent to which the reservoir affects and controls the delivery process downstream. In the suspended sediment there is a considerable increase in the fine proportion, which can be released out of the dams during flood periods and comes also from erosion of river banks. The decrease in the sediment flux exported by the Sebou River after the construction of the dams led to a 97% reduction in the coarse fraction deposited in the estuary. An increase of the fine proportion and reduction of the fluvial component could increase siltation in the estuary.

Introduction

The importance of human impact on sediment load of a river is highly variable since it depends on the type of activity and its application to the catchment. In Morocco, the high degree of climatic variability, the torrential nature of storm runoff, the low vegetation cover, the intense lithological vulnerability and the deforestation induced an important increase in sediment supply up to ten times the average value observed during the Quaternary period (Heusch 1970).

In the Mediterranean climate, low rainfall and great fluctuations in its distribution constitute a severe limiting factor for economic development. Because of this situation, Morocco began in 1975 a vast dam construction programme aimed at irrigating $1x10^6$ hectares before the year 2000 (DRPE, 1994) and producing some 5100 GWh yr^{-1} of hydroelectricity. Currently, there are 84 large dams, whose total capacity exceeds $10x10^9$ m^3 supplying water of 772,000 ha of irrigated land. Reservoir sedimentation represents a serious problem for water supply management and for the morphological equilibrium of the coastline. The construction of dams and other sediment retention systems can reduce downstream suspended sediments by 80-98% (Duhamel, 1973). Other environmental effects of dam construction on the physical, chemical, and biological characteristics of disturbed rivers have been reported from most continents (Bishop and Bell 1978; Ward and Stanford 1979; King and Tyler 1982; Walker 1985; Davey *et al.* 1987; Barrow 1987; Xu 1996).

The main purpose of this paper is to define the important impact of the construction of dams on sediment discharge supply to the Sebou estuarine zone. In this study an effort has been made to quantify the water and the sediment discharge before and after the construction of dams and to examine their effects on the dynamics of the sediment in the coastal zone.

Physiographic basin and regulated river

The Sebou River is one of the largest Moroccan rivers, draining approximately 40,000 km^2 (Figure 1). It runs across some 600 km from its sources in the Middle Atlas to the Atlantic Ocean. The physiography of the watershed is strongly influenced by the altitude distribution between the north and the south. The Sebou basin can be divided into three distinct geomorphic regions: the upper, mid and lower Sebou. The upper Sebou rises to over 2,800 m in the Middle Atlas mountains and is underlain principally by calcareous rocks. Its mean annual precipitation is over 1,000 mm and its winters are snowy at higher elevations. The mid-Sebou basin is located in the Rif and the Prerif Mountains, which are characterised by mid-altitudes averaging 2,000 m, very steep slopes, a strong rainfall gradient across the basin averaging 2,000 mm/year and a substratum consisting of schist, marl and marly sandstones. Among the major tributaries of the

Sebou draining the Rif and the Prerif Mountains, the Ouerrha and Inaouene are the predominant rivers in the basin. The lower Sebou enters the riverine plain and from there follows a highly sinuous course to the Atlantic Ocean. The estuarine system extends over 90 km of the lower Sebou, which has tidal influence.

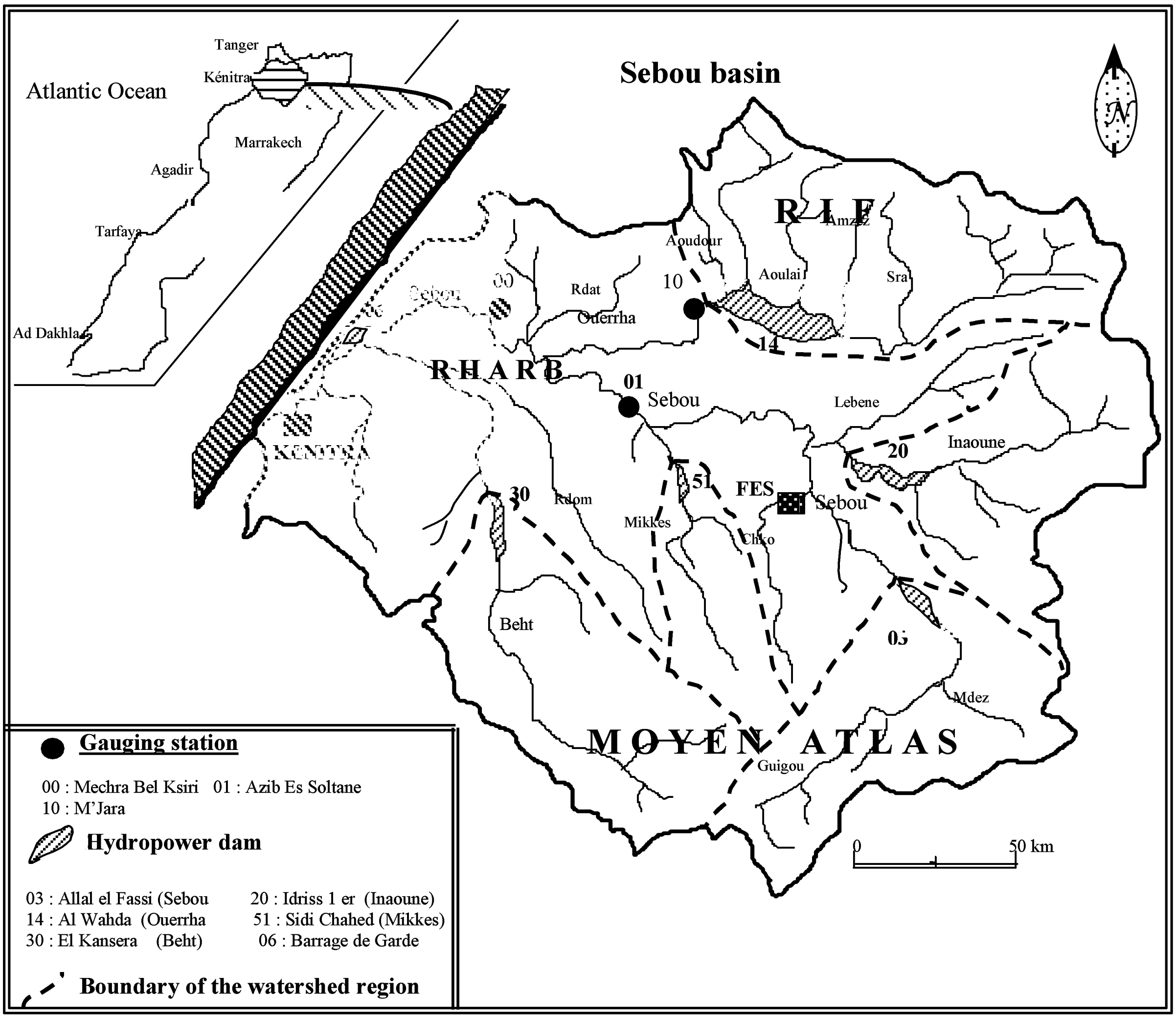

Figure 1. Geographic situation of the Sebou watershed showing major dams and gauging stations where data were collected.

In the Sebou basin, construction of dams began in 1935 with El Kansera reservoir on the Beht River. It was initially used for flood retention and later for water storage. By 1973 there were at least 15 dams in the Sebou basin, with five large reservoirs and 10 small dams. These reservoirs are now a major source of irrigation and drinking water and they strongly regulate the flow in the upper, middle and lower catchment. The Al Wahda dam constructed on the Ouerrha River is the second most important dam in North Africa after the High Aswan dam. It was constructed between 1991 and 1996 with a storage capacity of 3.8×10^3 km^3 for a height of 88 m. This reservoir will provide long-term storage, irrigate 100,000 ha, generate a hydroelectricity potential capacity of 400 GWh yr^{-1}, transfer a water capacity of 600×10^6 m^3 towards the southern regions and protect the Gharb Plain from high floods.

Materials and methods

This study is based on data obtained from gauging stations operated by the Water Planning Research Directory (DRPE). At each gauging station, DRPE measured water discharges rates and suspended sediment concentrations. Data from different stations provided estimates of the amount of sediment trapped by the dams. The available data from DRPE (1970; 1973) and Duhamel (1973) are utilised for the calculation of the weighted mean water and sediment discharge rates before the construction of the dams. The present-day water and the sediment discharge rates of the Sebou River are calculated by a measurement and quantitative sampling program that have started since 1996 shortly before the Al Wahda dam was used for water storage. Suspended sediments were sampled to quantify the net change in the sediment discharge and the grain size composition after the construction of the dams.

Results and discussion

Water discharge before and after the construction of the dams

The mean annual water discharge for 1940 to 1973 (before the construction of the principal dams) of the downstream gauging station of the Sebou river (Mechra Bel Ksiri) and of the estuary zone were respectively about 5.1×10^9 m^3 and 5.9×10^9 m^3. During this period, the water discharge contribution of the upper Sebou and its affluents to the Sebou downstream was about 2.55×10^9 m^3 (Figure 2). The construction of the Idriss 1er dam on the Inaouene River reduced the inflowing water supply by 42%. In 1990 the Allal El Fassi dam constructed upstream on the Sebou River was put into service, reducing the downstream water discharge of the Sebou River by about 54%. Between 1973 and 1995, the Ouerrha River carried most of the water discharge to the downstream of the Sebou. During maximum flood events the water discharge of the Ouerrha River inundated large portions of the adjoining floodplain and caused considerable damage to people and property (DRPE, 1970; 1973). To protect the flood-prone territory, the Al Wahda dam was constructed to control the Ouerrha River. As of 1996/97, the closure date of the Ouerrha, the average annual flow carried by this river to the downstream was reduced by 45%.

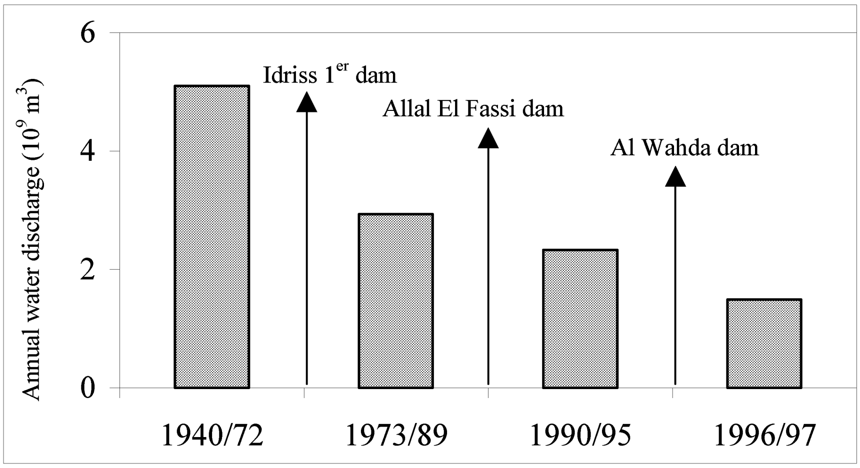

Figure 2. Variation of the annual water discharge at the downstream of the Sebou River before and after the construction of the dams.

Like all Mediterranean rivers, the Sebou River is subjected to climatic interannual irregularities. These have an important effect on the water discharge, particularly during dry periods when the reservoirs are used for water storage and very little of the inflow water is released. Figure 3 shows, in the Sebou, the relationship between the annual water discharge of the Sebou and the mean annual rainfall for a period of more than 32 years (1962-1994). The available data shows two opposite trends, before and after the construction of dams. In the Sebou the correlation between flow and precipitation is better before the dam construction (1962-1972) than after its construction (1973-1994). During this latter period the water discharge of the Sebou River has decreased independently of annual runoff. Possible reasons for this trend may be the effect of dams, the high evaporation intensity and the excessive use of water for irrigation during the drought period (Haida *et al.* 1999).

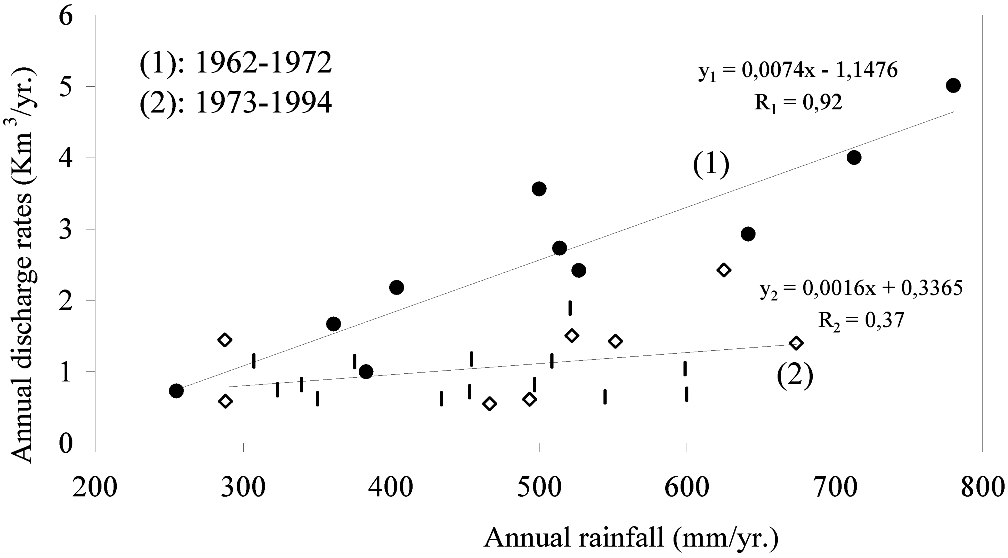

Figure 3. Relationship between the annual water discharge and the annual rainfall on the Sebou River at Azib Es Soltane during the two periods of 1962 to 1972 and 1973 to 1995 before and after dam constructions, respectively.

Suspended sediments discharge before and after the construction of the dams.

Before the construction of the dams on the main tributary of the Sebou River (1940-1972), the average suspended sediment input to the Atlantic Ocean was about $34x10^6$ t yr^{-1} (Figure 4). The estimated mean annual sediment yield in the Sebou basin is 850 t km^{-2} yr^{-1}. This value is comparable to those of other Mediterranean areas (Tronto, Italy: 900 t km^{-2} $yr^{-1}$and Esino, Italy: 800 t km^{-2} yr^{-1}: in Milliman and Syvitski 1992); Metauro, Italy: 870 t km^{-2} yr^{-1}: IAHS/UNESCO 1974).

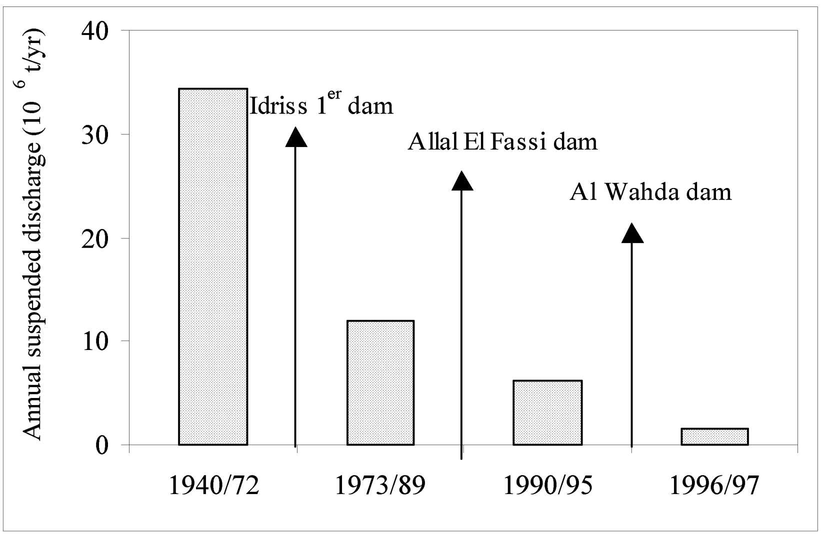

Figure 4. Variation of the suspended sediment discharge at the downstream of the Sebou River before and after the construction of the dams.

During this period 70% of the total material coming from erosion in the upper and middle reaches of the Sebou basin were carried to the Atlantic Ocean and 30% were deposited on the flood plain. With the construction of Idriss 1er and Allal El Fassi dams (1973-1995), the downstream suspended sediment fluxes decreased to $12x10^6$ t yr^{-1} and $6x10^6$ t yr^{-1} respectively. Consequently, the suspended sediment supply by the Sebou River to the Atlantic Ocean was reduced about 73 % in comparison with the sediment flux measured before the construction of dams. In 1996, after the Al Wanda dam came into operation, the sediment discharge measured downstream in the Sebou River has decreased to $1.6x10^6$ t yr^{-1} corresponding to a net reduction of water supply about 95%. This value is approximately similar to the trap efficiency value (from 85% to 99%) calculated by Haida *et al.* (submitted) and Haida (2000) for the dams constructed on the Sebou River and its affluents. Obviously, reservoir dams can intercept most of the sediment coming from the upstream River basin, and, thus, considerably reduce their storage capacity. According Haida *et al.* (submitted), their useful lifetime varies from 42 to 910 years. The short time that it takes for these reservoirs to be filled with sediment makes it necessary to consider sedimentation as a serious problem. In addition, reservoir sedimentation can have other serious implications on the evolution of the coastal plain. The river damming activities combined with the expansion of coastal towns, the development of beach tourism, sand extraction for construction purposes and the construction of ports, jetties and defensive structures have greatly altered the natural evolution of the coast (Snoussi *et al.* submitted).

Variation in grain size of the suspended and deposited sediments

During the pre-dam period, the size of the suspended sediment in the lower Sebou River showed the following proportions: 2% of sand, 52% of silt and 46% of clay (DRPE 1970) (Figure 5). After the construction of the dams, fine sediment was released through the dams preferentially over coarse sediment, so that the suspended sediment is dominated by the fine fraction (75% of clay) released out of the dams especially during the flood events; it also comes from bank erosion. Similar studies show that after the construction of dams, erosion rate increased (Colombani 1977) and the variation in the size composition of the sediment load depends on the delivery processes downstream (Xu 1996; Milhous 1997; Al Ansari and Rimani 1997).

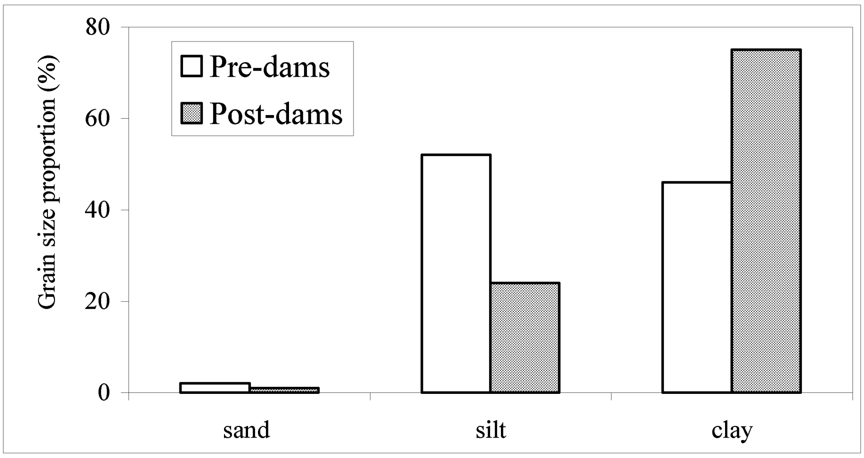

Figure 5. Grain size of the suspended load in the downstream of Sebou river before and after the construction of the dams.

Impact of the damming activities on the sedimentary dynamics in the Sebou estuarine zone.

Before the construction of the dams on the upper and on the middle parts of the Sebou basin, the sediment fluxes carried by the Sebou River to the Atlantic Ocean were mainly composed of fine elements. The proportion of the sand deposed in the estuary was approximately 2%. Thus, we can calculate the amount of sediments deposited in the estuarine system using the proportions of the sand and the fluvial suspended fluxes. The annual deposited sediments in this system is about 680 000 t/yr. According to DRPE (1970), dredging is an efficient means to keep a draught of 4.5 m for navigation purposes. During the period 1954 to 1967 the dredging has varied from 1,920,000 t yr^{-1} to 660,000 t yr^{-1}. Other installations are planned for this estuary system. Defensive structures have been constructed on many parts of the banks to keep back fluvial sediments and to create a navigable channel with a strong current.

After the construction of the Idriss 1er, Allal El Fassi and Al Wahda dams (1973-1996), the sediment fluxes supplied by the Sebou River estuary was reduced about 95%. Suspended sediments are still dominated by the fine fraction. However, the clay fraction increased after the construction of the dams. The annual mean deposited sediment in the estuarine zone is about 16,000 t yr^{-1}, which is 43 times less than before the construction of the dams.

Conclusion

The variations observed in the water and the sediment discharges after the construction of the dams reflect their effects on the physical characteristics of the Sebou basin and the estuarine zone.

Downstream, the water discharge of the Sebou River and its affluents was reduced after the construction of the dams by about 70%. More than 95% of the total sediment load had been trapped by all the reservoirs. Consequently the sediments will quickly fill these reservoirs and cause a considerable losses of their capacity. After the construction of the dams, the suspended sediment grain size exhibits a high proportion of fine sediments (75%). This fining tendency is induced by the combination of fine sediment release from the dams especially during the flood events and by bank erosion, which intensified after dam construction. Damming has also affected the amount of suspended sediment supplied to the estuarine zone. Thus, the decrease in sediment flux exported by the Sebou River after the construction of the dams led to a decline in the sand fraction deposited in the estuarine system. With the decrease of the fluvial competence, the Sebou River estuary will become more heavily silted and the defensive structures could induce important modifications in the natural evolution of the coast.

The results of this study are preliminary; more detailed measurements of suspended sediment discharge and reservoir siltation are required to provide a definitive assessment of reservoir sedimentation problems and their effects on the river downstream and the estuary system.

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4.6 Behavior of heavy metals from land to coastal zone through estuaries: Moroccan case studies

Maria Snoussi

Abstract
Base-line studies have been carried out on the trace metal contents of bottom sediments of three Moroccan estuaries and their catchment drainage, representing both contaminated and relatively uncontaminated environments. The levels of trace metal (lead, copper, zinc, nickel) concentrations when normalized against aluminium concentration indicated contamination with one or more of the elements at most of the estuarine and marine stations.

In the Sebou River, the enrichment of estuarine sediments in comparison to the background levels is attributed to land-based point sources of pollution located along the river and estuarine banks. It is likely that the Sebou River estuary acts as a trap for heavy metals. In the estuaries of the Tensift and Souss rivers, the estuarine sediments are low in heavy metals. This could mean that these systems facilitate the release of heavy metals from sediments and hence regulate their fluxes to the ocean. On the other hand, the enrichment of some metals in the marine sediments is attributed to mixing with contaminated sediments which have come from polluted areas and ports (Safi, Agadir) and have been transported southward by the littoral drift.

Introduction

Rivers are the major routes from the land to the sea of the natural products of weathering and of many man-made materials. Economic activities and household consumption generate significant pollutants into rivers and coastal zones. Among them, non-biodegradable heavy metals have great ecological impact due to their toxicity and accumulation. Before entering the ocean, heavy metals must pass through estuaries which are interfaces of high biological productivity. Major cities and harbors are often located in estuaries, thus further disturbing natural conditions.

Much of the anthropogenic heavy metals discharged into the estuaries becomes suspended in rivers. The estuarine distributions of trace metals can be interpreted in terms of geochemical processes such as flocculation, precipitation, adsorption/desorption, and also in terms of mixing processes and biological cycling (see Martin *et al.* 1976; Salomons and Förstner 1984; Jouanneau *et al.* 1983).

In the hydrological cycle that governs the fate of metallic elements, sediments play an essential role to the extent that they are increasingly recognized as vectors, principal sinks and potential sources of a great number of toxic metals. Thus, sediment analysis is an important tool to trace man-caused pollution of water (Förstner and Wittman 1983; Senten and Charlier 1991).

This paper aims to describe the general behaviour of lead, zinc, copper and nickel from the soils to the adjacent coastal zones of three river basins, representing contaminated and relatively uncontaminated environments, to determine whether the estuarine sediments act as traps or sources of trace metals.

Study areas

Three rivers were selected for this study: the Sebou, the Tensift and the Souss. (Figure 1).

Detailed accounts of the physical setting of their drainage basins have been given in previous works (Snoussi 1988; Sahibi and Snoussi 1993; El Mouden and Snoussi 1994; Snoussi *et al.* 1992; Haï da *et al.* 1996; Haida 2000). In summary:

- The Sebou River, whose drainage basin covers an area of 40,000 km^2 represents one of the most populated, agricultural and industrial regions of Morocco. The lower reaches and estuarine zone of the Sebou flow through the city and harbour of Kenitra and have been impaired by the discharge of untreated sewage and industrial effluents. Tidal influence reaches the Garde dam (85 km), which was installed to restrict the salt wedge intrusion upstream.

- The Tensift River, with 19,850 km² of drainage area, runs through the large agricultural plain of Haouz and the metropolitan area of Marrakech. Except during rainy winters, the river flow of the mid-Tensift is dominated by domestic effluents. However, the flow is too weak to reach the sea, and the estuarine zone (5 km) is relatively unpolluted.
- The Souss River is a characteristic arid zone temporary river, draining an area of 16,100km². It is often dry in its lower reaches. The 5 km long estuarine zone traverses some small urban agglomerations. To the north of the estuary, the city and the big port of Agadir provide potential sources of both urban and industrial contamination.

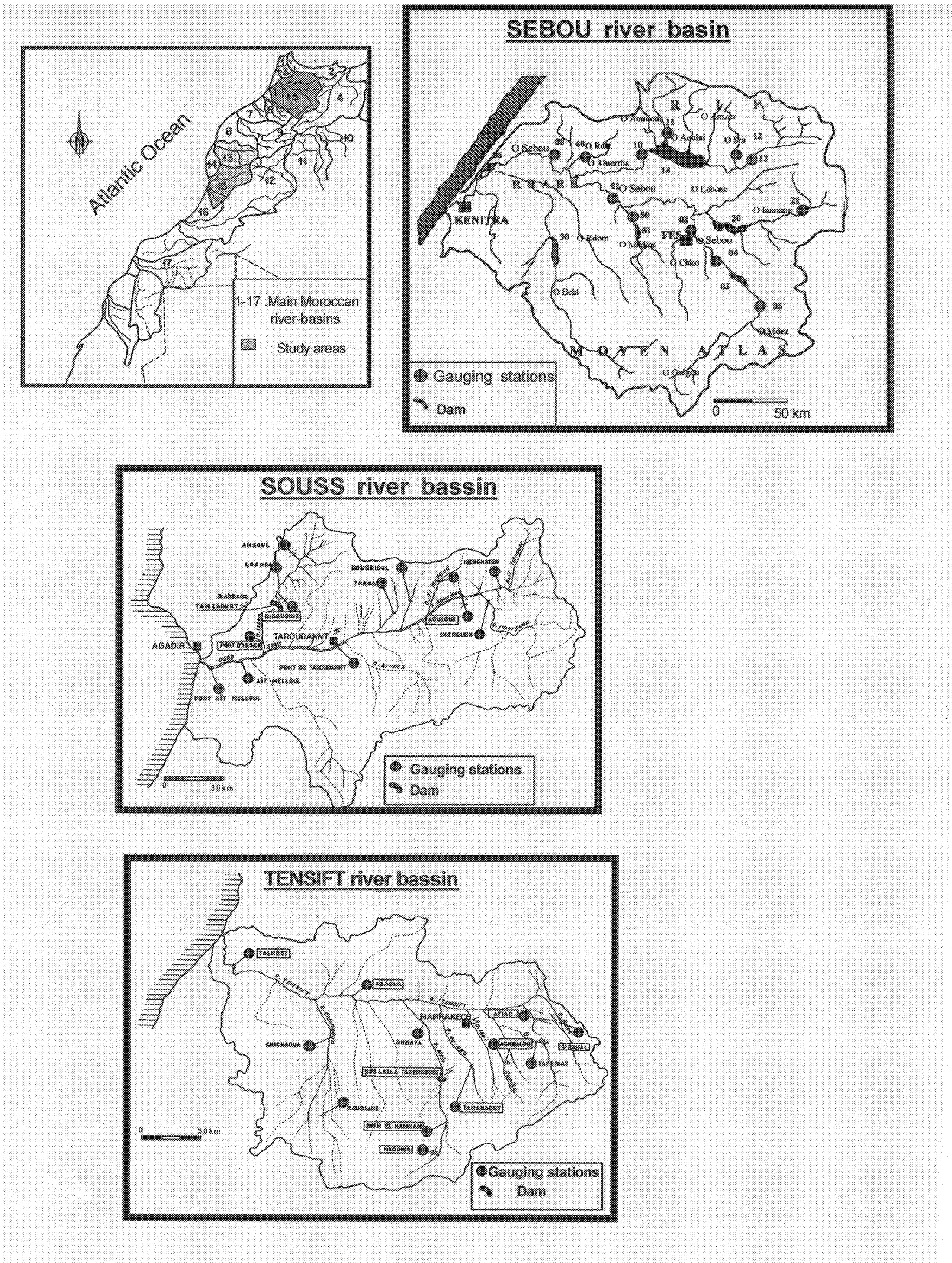


Figure 1. The basins of the Sebou, Souss and Tensift rivers, Morocco.

Materials and methods

A total of 45 samples of surficial sediments were collected from the Sebou, Tensift and Souss river basins and their adjacent coastal areas.

- Freshly deposited bed sediment samples were collected along the river bank, upstream of the limit of the tidal influence.
- In the estuarine section, samples were taken during low tides, from the limit of the tidal influence to the mouths of the rivers.
- Surficial marine sediment samples were collected at a series of offshore stations opposite the mouths of the rivers by a Schipeck grab from the French R/V *Noroit* during the Geomar cruise.
- Soil samples were taken in non-polluted locations within the river basins to establish the natural background levels for the rivers, in order to define the extent of potential pollution. Chemical analysis for Al, Cu, Ni, Pb and Zn was performed by the energy-dispersive X-ray fluorescence technique (XRF) on the bulk samples.

Results and discussion

The mean concentrations of trace metals in the soils and the sediments of the Sebou, Tensift and Souss river basins are given in Table 1.

Table1 : Mean concentrations of trace metals in soils, fluvial, estuarine and marine sediments in the studied areas.

	Average contents	**Al_2O_3** %	**Zn** ìg/g	**Ni** ìg/g	**Pb** ìg/g	**Cu** ìg/g
Sebou	Soils	11.7	103	42	23	78
	Fluvial sediments	10	85	35	20	73
	Estuarine sediments	12	111	42	35	78
	Marine Sediments	14	93	42	29	65
Tensift	Soils	11.6	83	5	37	29
	Fluvial sediments	15.4	129	54	35	36
	Estuarine sediments	13	96	42	27	22
	Marine sediments	10	125	30	24	28
Souss	Soils	12.7	55	30	11	63
	Fluvial sed.	14	70	34	15	71
	Estuarine sediments	9.8	59	29	11	57
	Marine Sed.	10	70	27	12	61

To provide a meaningful comparison between different results, as well as an assessment of the local anthropogenic contribution to the sediments, elemental concentrations were normalized with respect to a conservative element : aluminium was chosen in this study.

The average contents of heavy metals normalized to Al in fluvial, estuarine and marine sediments were compared to the natural geochemical background.

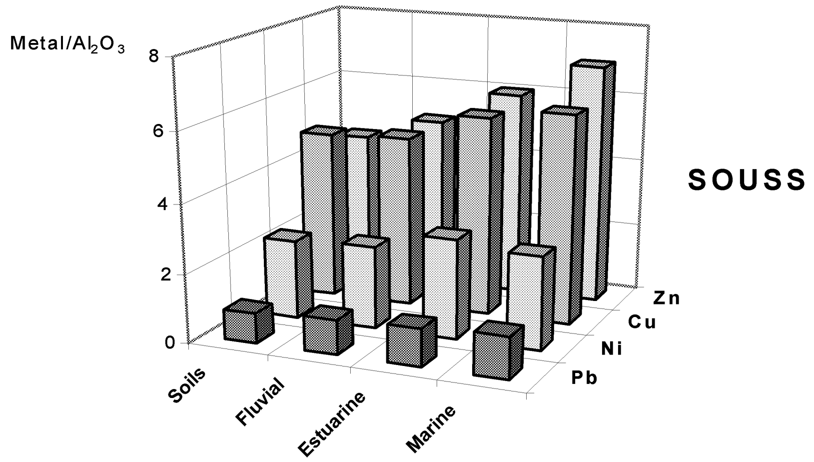
It appears that:

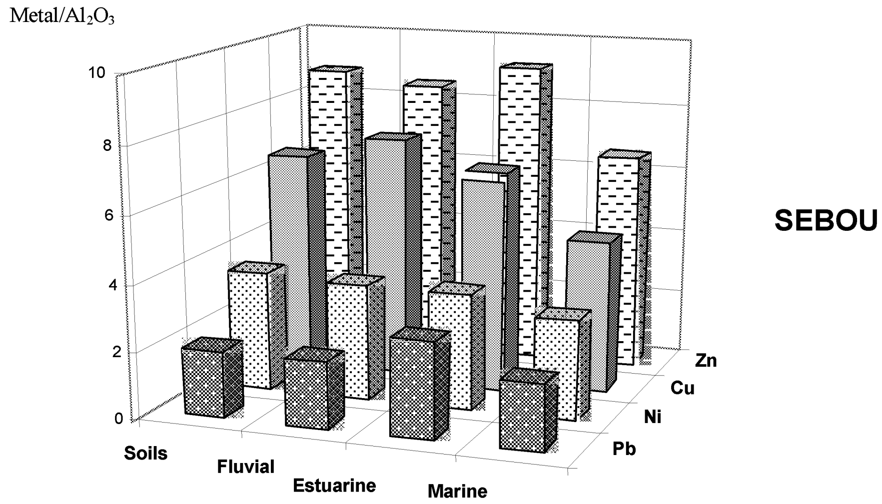
➢ in the Sebou River basin (Figure 2), average metallic contents are highest in the estuarine stations. This enrichment is attributed to contamination derived from both industrial and domestic effluents discharged directly into the estuary. The most probable source of Pb contamination is particles related to traffic (petrol combustion) along the estuary's banks. It is also likely that in the estuarine zone, the metals in solution could precipitate with iron-hydroxyde, which is known to act as an effective scavenger for a number of heavy metals (Goldberg 1954), depleting the water and enriching the sediment in heavy metals (Boyle *et al.* 1977; Sholkovitz 1978). Indeed, sediments derived from the Sebou lower estuary are enriched in iron oxides.

- In the Tensift River basin (Figure 2), normalized metallic contents are weaker in estuarine sediments than in fluvial ones. This phenomenon, common in many estuaries, can be attributed to the mobilization of metals caused by the formation of complexes between the metal ion sorbed to the sediments and organic ligands released by the intensive decomposition of organic matter (Bourg, 1983; Jouanneau *et al.* 1983). On the other hand, marine sediments are almost twice as rich in Zn than the background level and estuarine sediments. This enrichment is probably due to the transport of marine contaminated sediments brought by littoral drift from the industrial zone of Safi and mixing with impoverished estuarine deposits.
- In the Souss River (Figure 2), normalized data showed a seaward increase of Zn and Cu contents. This could be explained, as in the case of the Tensift, by a contamination coming from the sea and the port of Agadir. The analysis of some sediments sampled in untreated sewage discharged in the estuary showed that despite the strong metals contents of this urban effluent, estuarine sediments downstream of the discharge are not contaminated (Figure 3). This can be explained by the fact that the exclusively organic nature of this sewage entails the release of metals linked to the organic components. This would favor their evacuation at sea in the dissolved form.

To facilitate metallic content comparisons, "mobility factors" (M1 and M2) that represent ratios of normalized contents between marine sediments and soils on the one hand and between estuarine and marine sediments on the other hand were used (Figure 4) . These trends agreed with previous interpretations, namely:

- sediments of the Sebou are polluted by industrial and urban effluents discharged directly in the river and the estuary, while marine sediments are not contaminated. The Sebou estuary acts as sediment trap which apparently retains a large percentage of the particulate metals entering from rivers. This phenomenon is exacerbated by the progressive siltation of the estuary following the construction of many dams on the Sebou River (Haida 2000).
- estuaries of the Tensift and the Souss play the role of "releaser" for some metals, that are impoverished in sediments, while the pollution comes from the sea.





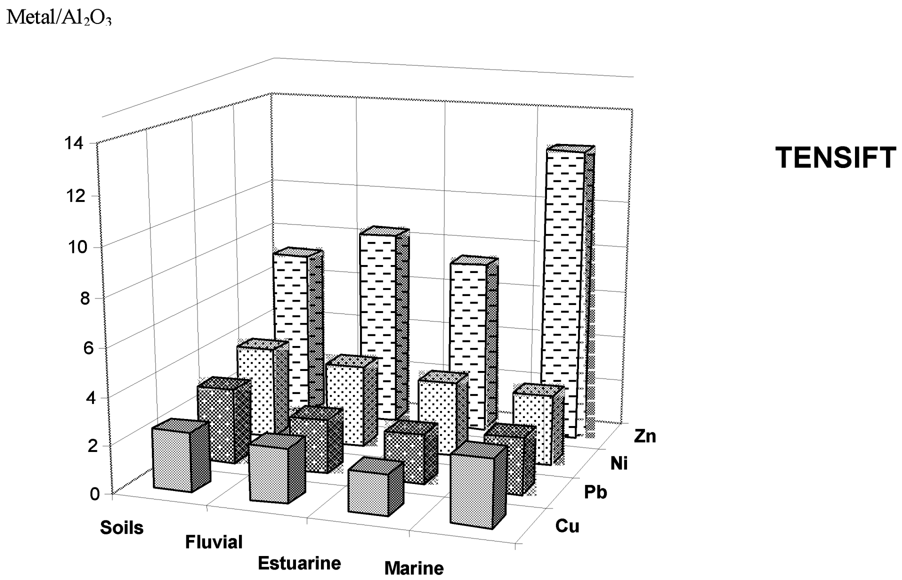


Figure 2. Comparison of the metal /Al_2O_3 ratio between soils and riverine, estuarine and marine sediments, in the Sebou, Tensift and Souss basins.

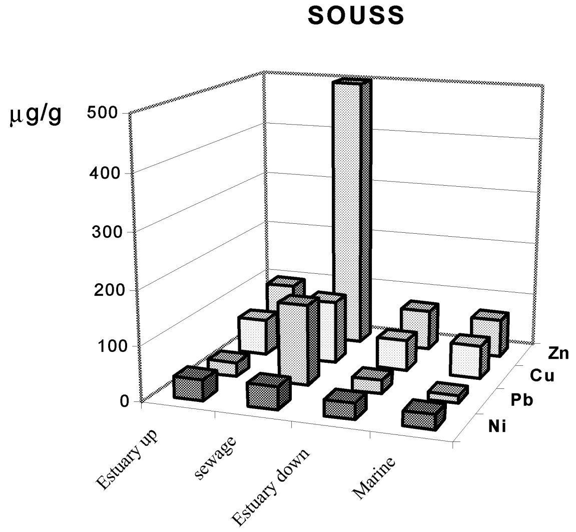


Figure 3. Average contents of metals in the Souss estuarine sediments upstream and downstream an urban effluent.

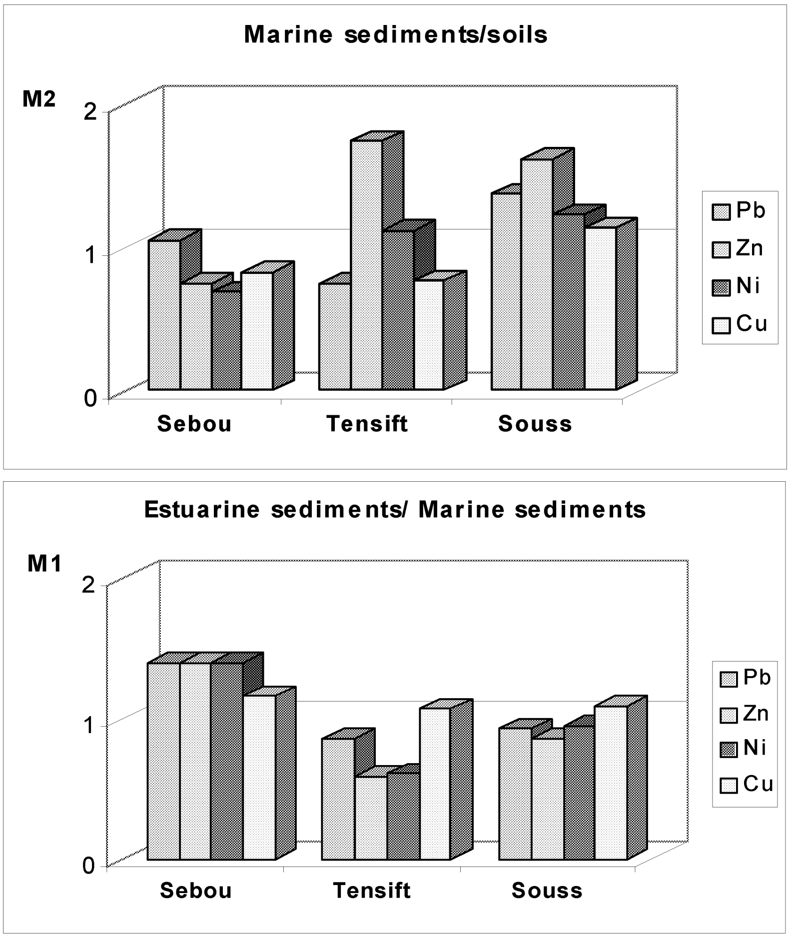


Figure 4. 'Mobility Factors': M1:metal/Al_2O_3 in marine sediments Metal/Al_2O_3 in soils and M2: metal/Al_2O_3 in estuarine sediments_metal/Al_2O_3 in marine sediments.

Conclusion

As environmental pollution has increased, sediment analysis has gained in importance because pollutants, such as heavy metals, are enriched in bottom deposits. By trapping metals, sediments act as reservoirs of potentially remobilizable metals and then represent risks for ecosystems.

In estuaries, as well as the control by hydrodynamic processes outside the scope of this study, the behavior of metallic elements is governed by chemical reactions that lead to the release or the trapping of trace metals. These processes regulate the fluxes of particulate and dissolved metals to the ocean. Estuaries can be seen as barriers preventing a large portion of river-borne solutes from entering and accumulating in the world's oceans. However, it is important to better understand estuarine processes to predict the geochemical behavior of each element as well as the role of these processes in the mass balance between rivers and oceans.

Chemical and hydrodynamic processes in Moroccan estuaries are still poorly understood. To get a better idea of these very complex mechanisms, it is necessary for further work to analyse metals and organic matter in waters and suspended particles.

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4.7 Coastal changes in response to the effects of dam construction on the Moulouya and the Sebou rivers (Morocco)

Maria Snoussi and Souad Haïda

Abstract

Sediment fluxes of the Moulouya and Sebou rivers - the two largest rivers of Morocco - were estimated on the basis of suspended sediment loads transported by these rivers towards the coast. It appears that the specific sediment yields of the Sebou (995 t/km²/yr) and the Moulouya (240 t/km²/an) are among the highest in Africa, due to the fact that the drainage basins are characterized by young, mountainous, extended erodible sedimentary rocks, irregular and often stormy precipitation and scarce vegetation.

In recent times these sediment loads and water discharges have been drastically reduced as result of dam construction and changes in rainfall regimes. It is estimated that the construction of dams has reduced the water discharge of the Sebou and the Moulouya rivers by 70% and 47%, and their sediment fluxes by nearly 95% and 94%, respectively.

Damming of rivers appears to have had a profound effect on the coastal zones, which react by achieving a new sedimentary equilibrium. The forcing induced by the estuarine behavior of the lower stretches of both rivers downstream of the dams has greatly disturbed the mouth topography and coastal stability.

Key-words: Sediment yield - Moroccan rivers – dams – siltation - coastal morphology.

Introduction

River sediment fluxes constitute one of the main components of the coastal sedimentary budget. Any change of these fluxes may significantly alter the physical environment of the coastal systems (Hay, 1994; Simeoni and Bondesan 1997; Poulos and Chronis 1997; Barusseau *et al.* 1998).

As a semi-arid region, Morocco faces periodic rainfall deficit due to recurrent droughts. In order to better manage these shortages, a large-scale program of dam construction has been carried out over the last decades for drinking water, irrigation and hydroelectric power (DRPE, 1994). However, these reservoirs suffered from siltation due to the high rate of natural and accelerated erosion of the hinterlands. According to Lahlou (1996), the annual sedimentation rates in Moroccan reservoirs reached 50×10^6 m³/yr. This huge siltation has a serious environmental and socio-economical impact, since it reduces the reservoir capacity and may affect the morphological equilibrium of the coastline.

This paper provides data on the water and sediment fluxes of the two largest rivers in Morocco: the Moulouya and the Sebou rivers that flow respectively into the Mediterranean Sea and the Atlantic Ocean. The main objectives are to investigate the role of one component of the coastal sedimentary budget, the trapping of river sediment within reservoirs, and to examine the geomorphological response of the coastline to the human activity of building dams.

The river systems (Figure 1)

Moulouya River

The Moulouya River is the largest river in Morocco, draining approximately 53,500 km² of eastern Morocco. It rises in the Atlas Mountains and flows into the Mediterranean Sea. The basin is characterized by heterogeneous topography and lithology, and by arid and semi-arid climatic conditions, with predominantly seasonal streams. Annual precipitation ranges from 200 mm to 600 mm and occurs in only a few days. The upper region, mountainous and hilly, is separated from the lower floodplain by the large Mohammed V reservoir which traps most of the sediment delivered from the upper basin.

Sebou River

The Sebou River covers a total drainage area of approximately 40,000 km². It runs through about 600 km from its sources in the Middle Atlas Mountains to the Atlantic Ocean. Two mountainous chains surround the drainage basin: the Rif Range to the north, drained mainly by the Ouerrha River, which has a torrential regime during flood periods; and, to the south, the Middle Atlas and the Plateau Central, drained by the Sebou and other tributaries whose regimes are more regular and are fed by the snowmelt. The climate is sub-humid to semi-arid. The mean annual precipitation ranges from less than 500 mm in the Rharb Plain to more than 2000 mm in the Rif Mountains.

The Sebou River basin is one of the most populated regions of Morocco. In 1990, its population was about 5 million of which 61% lives in rural zones. It represents the most important agricultural region of the country and has a relatively developed social and economic infrastructure. The basin encompasses seven large reservoirs and at least ten small ones built over a period of 70 years.

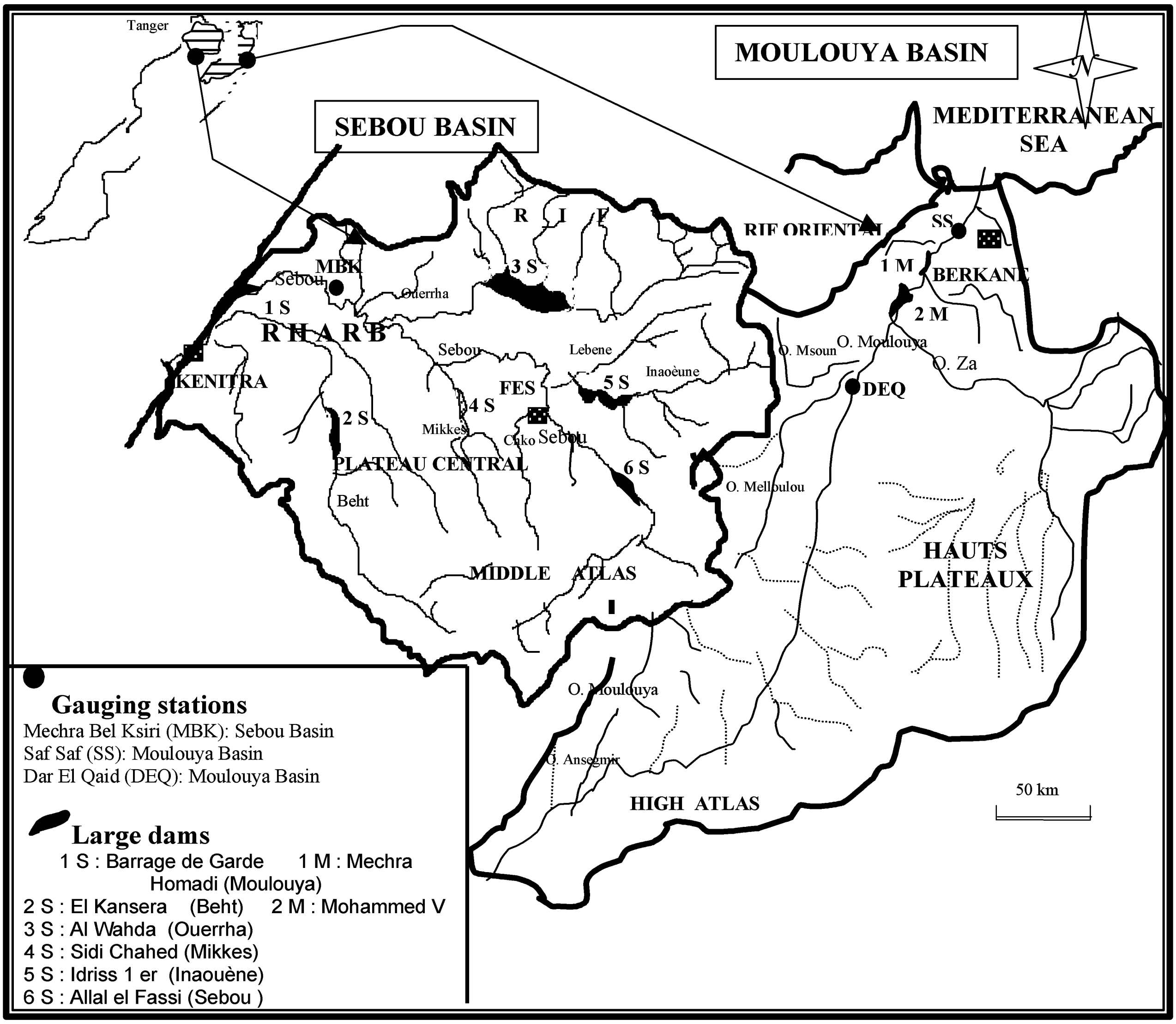

Figure 1. Geographic situation of the Sebou and the Moulouya watersheds showing major dams and gauging stations where data were collected.

Data and results

Data on water flows and suspended sediment concentrations used in this study were obtained from four gauging stations operated by the Water Planning and Research Directorate (DRPE) who provided the information on the status of dams.

Water and sediment fluxes

Impact of dams on water fluxes

Table 1 presents for each river, the drainage basin area, the river runoff and the mean annual water discharge at the furthest downstream flow gauging stations: Mechra Bel Ksiri (MBK) for the Sebou and Saf Saf for the Moulouya.

Table 1. Drainage basin area, mean annual water discharges and specific water flow at the downstream gauging stations on the Moulouya (Saf Saf) and the Sebou rivers (Mechra Bel Ksiri).

	Gauged drainage basin		Period of data collection	Mean annual discharge ($m^3 s^{-1}$)	Mean annual flow 10^6 m^3	Annual runoff (mm)
	(km^2)	(%)				
Moulouya (Saf Saf)	49 920	93	1970-1996	13	410	8.2
Sebou (Mechra Bel Ksiri)	26 100	65	1940-1994	131	4 127	158

As outlined above, the Sebou River system is heavily regulated and the flow regime has been significantly altered. Haida *et al.* (submitted) estimated the water discharges before and after dam construction and concluded that dams have reduced water discharge to the coast by approximately 70%. In the Moulouya River, water discharge has been reduced by about 47% due to the construction of the Mohamed V reservoir.

Impact of dams on sediment fluxes:

Available data on suspended sediment in the Sebou basin are relatively comprehensive and cover a long period, whereas they are far more fragmentary and discontinuous for the Moulouya River. The annual suspended sediment discharge and yield are presented, together with corresponding water discharges in Table 2.

As can be seen from this table, the Sebou River has a mean specific suspended sediment yield four times higher than that of the Moulouya River. This value is also higher than that estimated by Snoussi *et al.* (1990) for the Moroccan Atlantic rivers (750 t km^{-2} yr^{-1}) and by Probst and Amiotte-Suchet (1992) for the whole Maghreb region (610 t km^{-2} yr^{-1}). This exceptionally high sediment yield of the Sebou River is due to the combination of the steeper slopes that often generate mass movements, such as landslides and mudflows (Heusch and Milliès-Lacroix 1971), the extended, easily erodible sedimentary rocks of its drainage area (Haida 2000), the high precipitation rates and human activities such as vegetation clearance and land-use change.

The Sebou River basin provides an interesting case study for examining the effects of reservoir construction on river sediment fluxes. Haida *et al.* (submitted), have estimated the mean suspended sediment flux prior to dam building (1940-1972) at about 34.3×10^6 t yr^{-1} at the Mechra Bel Ksiri gauging station. After the construction of different dams on the rivers, the sediment yield was not more than 1.63×10^6 t yr^{-1}. Thus, more than 95% of the total sediment load had been trapped. Haida (2000) reported that for the Sebou and its tributaries, the mean trapping efficiency of dams ranges from 85 to 99%, and the lifespan of the dams ranges from 42 to 910 years.

For the Moulouya River, the construction of the large Mohammed V reservoir, combined with more frequent droughts since 1980, has led to a drastic reduction in sediment supply to the coast. Prior to dam construction, the Moulouya transported an average sediment load of 12×10^6 t yr^{-1} to the coast. Unfortunately, no suspended sediment data for below the dam are available. However, assuming a 94% calculated trap efficiency of sediment by the dam, it can be estimated that the Moulouya River delivers nowadays to the Mediterranean Sea only 6% of the load transported before dam construction. Its lifespan is estimated at about 85 years.

Table 2. Mean annual water and suspended sediment fluxes in the Sebou and in the Moulouya drainage basins.

River	Gauging station	Area (km^2)	Period of data	Mean annual water discharge 10^6 m^3	Mean annual suspended sediment load & yield	
					10^6 t yr^{-1}	t km^{-2}/yr^{-1}
Sebou	Mechra Bel Ksiri	26,100	1940-94	4 127	26	995*
Moulouya	Dar El Qaid	24 422	1950-88	700	7	287*
	Mohamed V dam	49 920	1961-90	1000	12	240**

* from measured values   ** from the reservoir sedimentation

Changes in coastal morphology

As the coasts are geomorphological features resulting from the existence of a balance between the dynamics of the continental drainage basin and the dynamics of the marine receiving basin, they may be very sensitive to any natural or anthropogenic change occurring in one of these systems.

The Moulouya coastal plain provides an interesting case study for examining the effects of natural and man-induced changes on the shoreline morphology. These changes were investigated by Zourarah (1994) and Zarki (1999) using topographic maps and the comparison of two sets of aerial photographs (1958-1988) of the region. Over about 40 years, the river has made the following changes :

- In 1958, the lower Moulouya River course was sinuous to meandering, and the river mouth was much wider than present, with an oblique angle to the coastline (Figure 2). The fluvial load was heavy enough to lead to the progradation of deltaic deposits in the eastern part of the river mouth.
- In 1963 the Moulouya River basin was subjected to major floods (the largest ever recorded) that caused important changes in the morphology of the channels and the coastline. The floods caused interruption in the natural levees, and the channel made a short cut resulting in a straighter and shorter course. The littoral bars were eroded.
- After the 1963 floods, the lower river developed a braided channel morphology with a narrow channel and sandy bars.
- In 1967 the Moulouya River underwent damming and land management changed as a result of social influences. The river mouth and the coastal zone reacted with remarkable adjustments, consisting primarily of a change from a deltaic system to an estuarine system, and resulting in the erosion of the coastline.

Indeed, as the fluvial sediment load has greatly attenuated since the dam construction, and because of the weak fluvial hydraulic power, the marine factors have been reinforced, leading to reworking of the shoreline sediments, the narrowing of the mouth area and the development of mouth bars. These changes can be explained within the hydrodynamical and sedimentological context of the coastal zone. According to Zourarah (1994), the most frequent waves come from the east (44.5%) and from the west (30%). The significant wave height ranges between 1 and 2.5 m. With regard to longshore transport, the most effective waves and the induced sand transport are directed westwards. The net littoral transport is approximately 165,000 m3/yr. The sand transported was responsible of the accretion of the west coast, while the east coast, not fed by fluvial inputs, was retreating.

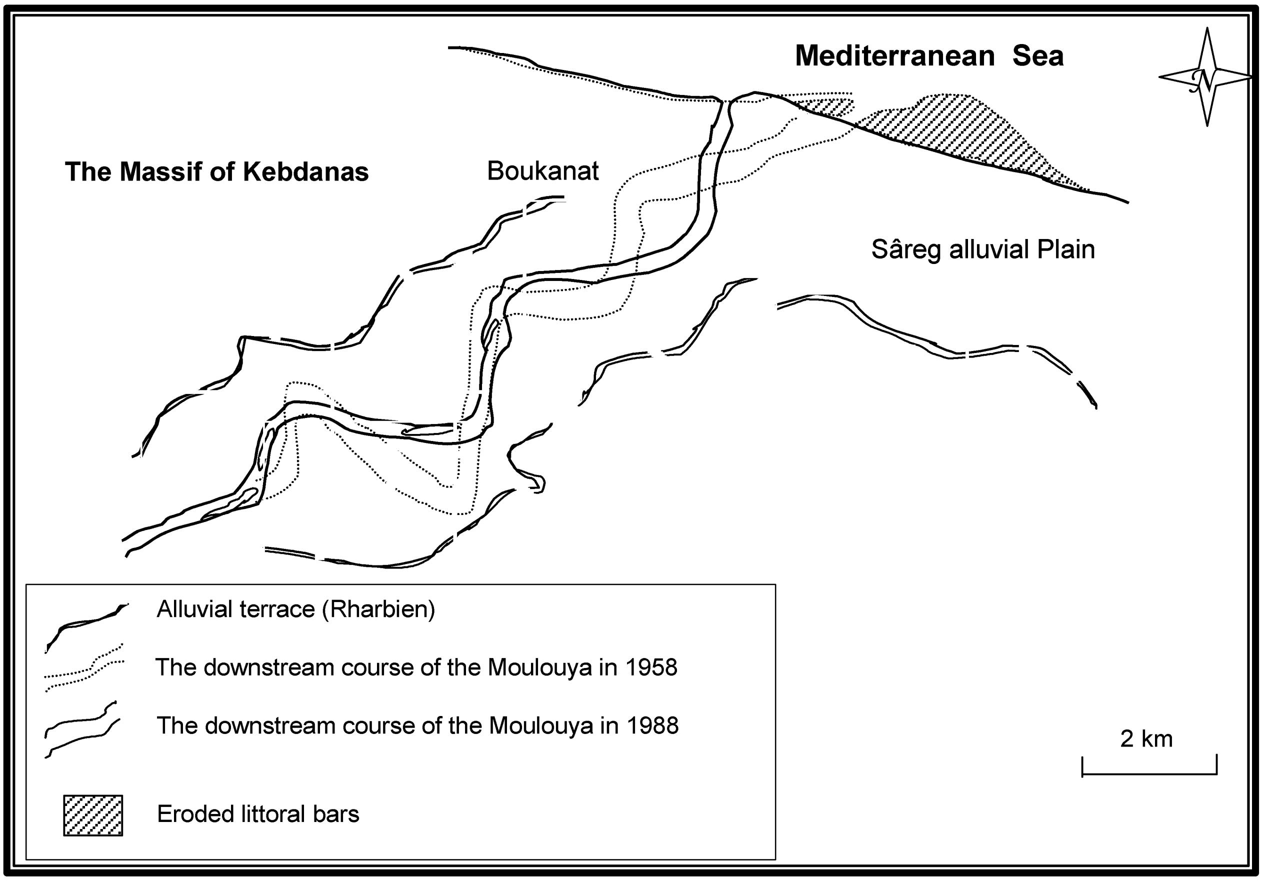

Figure 2. Historical evolution of the lower course of the Moulouya River and of the coastal morphology (from Zourarah 1994, modified).

It is more difficult to link the shoreline evolution of the Sebou coastal plain to the river damming activities, since the causes of this evolution are manifold and affect the coast at different rates and times.

Indeed, as well as the fact that the Sebou River is heavily regulated (78%), the huge population moving from the country to the coastal towns, the development of beach tourism, sand extraction for construction purposes, the construction of ports, jetties and defensive structures, combined with presumed sea-level rise, have interfered with the river basin activities and deeply altered the natural evolution of the coast.

According to investigations carried out for the Sebou Project (1970), it has been estimated that an average of 700,000 m^3 of fluvial sands were deposited annually within the estuary, considerably restricting navigation. Indeed, a shoal culminating to 2m below low tide formed regularly between the jetties. In order to maintain an adequate depth in the navigational channel, it has been estimated by the Public Works authorities that a dredging of 800 000 m^3 is required annually.

> Nowadays, due to dams impoundment, the fluvial competence has become too weak for dispersing all the littoral transit, in spite of the relative importance of the tidal currents within the lower estuary. Moreover, as some dams were constructed for controlling flood discharges and coastal plain inundation, it is likely that the estuary is not flushing as frequently as before and it will become the site of enhanced siltation (Collins and Evans 1986).

Conclusion

The recent evolution of the Sebou and the Moulouya coastal zones is governed by different land-ocean interaction processes, supplemented by anthropogenic activities. The latter can cause a chain of impacts on the natural continuum of transfer of sediments from uplands to the coastal zone. Some of these impacts were evident from this study:

- The natural erosion rate is high in the Sebou and the Moulouya basins. It is however accelerated following the land-use changes, leading to serious losses of arable lands. For example in the Moulouya river basin, it is estimated (M.A. 1996) that by the year 2030, 70,000 ha of irrigated land and 300×10^6 kWh of electricity will be lost. In terms of replacement costs, this loss is equivalent to an annual economic loss of more than 950 million dirhams (about $100 million). This estimate does not include the other direct and indirect effects on the environment, economic development and workmanship.
- Accelerated siltation of reservoirs compromises their storage capacity and shortens their life span. These reservoirs are indispensable to manage water resources under this type of climate.
- By reducing river supply, these reservoirs have also an impact on the morphological equilibrium of the shoreline. The impoundment of flow discharges, by modifying estuarine circulation and strengthening the marine hydrodynamical action, is responsible for coastal erosion/sedimentation, as noted by Barusseau *et al.* (1997) for the Senegal River after the construction of Diama dam. The siltation of estuarine zones entails costly dredging operations.

Thus although dams have obviously many socio-economic benefits, mainly in the semi-arid regions, these benefits are sometimes outweighed by their social, environmental and economic costs. One way to avoid such negative impacts is to introduce environmental indicators within economic budgets.

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4.8 Modifications morphologiques dans la zone de l'embouchure du fleuve Sénégal après la construction du barrage de Diama

Alioune Kane

Introduction

La formation du delta du Sénégal remonte à la période post-nouakchottienne (6 800–4,200 BP?) qui correspond à une régression consécutive à une baisse du niveau marin. Une lagune s'est ainsi formée derrière un puissant cordon littoral. La morphologie du cours inférieur du fleuve Sénégal est celle d'un delta (Coleman et Wright 1975) dont les affluents ont été recapturés à l'Holocène, par le cours principal brusquement détourné vers le sud (Michel 1973; Monteillet 1988). Le delta du Sénégal a été classé (Coleman et Wright 1975) parmi le type extrême des deltas à prédominance très nette des effets de houle, qui a pour résultat une dérive littorale édifiant des cordons littoraux parallèles à la côte.

A la suite de la construction du barrage de Diama en novembre 1985 sur le cours inférieur du fleuve Sénégal, la partie estuarienne de la vallée, la zone d'embouchure et la zone côtière adjacente ont connu des transformations importantes.

Approche géomorphologique

L'estuaire du fleuve Sénégal est désormais limité en amont par le barrage anti-sel de Diama, tant que ses vannes restent fermées, et à l'aval par son embouchure, unique exutoire par laquelle remontent les eaux marines (Figure 1).

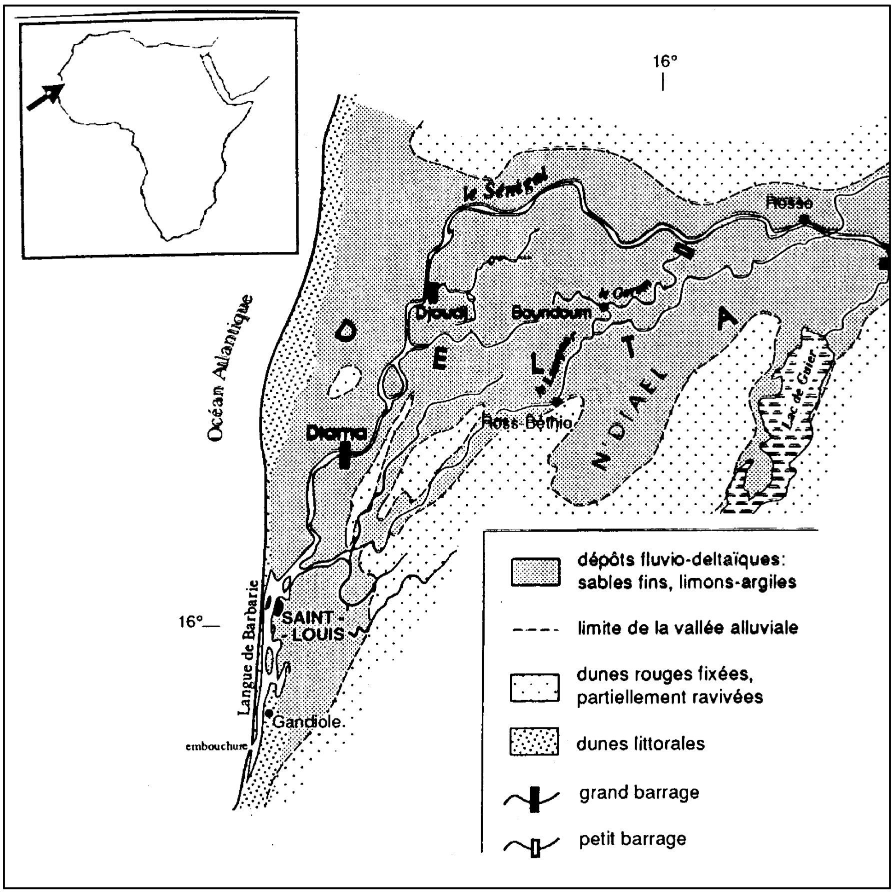


Figure 1. Carte de situation du delta du fleuve Sénégal (Michel *et al.* 1992).

Dans l'ultime partie de son cours, le Sénégal abandonne la direction est-ouest pour obliquer vers le sud et longer la mer en s'en rapprochant progressivement. Au niveau et en aval de la ville de Saint-Louis, le fleuve n'est plus séparé de l'océan que par un unique et mince cordon sableux de largeur décroissante du nord au sud constituant la Langue de Barbarie. Cette flèche littorale actuelle de sable fin blanc, qui est le plus récent des cordons littoraux du front deltaï que est le résultat d'un long processus alternatif d'engraissement et de démaigrissement de la plage par la dérive littorale.

Dans la zone côtière, la plaine d'inondation est étroite. Le Sénégal s'insinue dans des couloirs de largeur kilométrique, essentiellement sablo-argileux. Les alluvions fluviatiles sont limités à l'est par les dunes rouges continentales et, à l'ouest, par une succession de cordons littoraux qui constituent des alignements parallèles à la côte.

Le plateau continental, limité à l'isobathe 200 m, se prolonge sur près de 40 km au large de la région de Saint-Louis. Les relevés bathymétriques effectués au large par BBL-Sw (1985) montrent que le fond est relativement régulier. La pente, peu accusée, varie de 2 % à 1,66 % du rivage jusqu'à une profondeur de 10 mètres, au large de ce point, la pente devient moins accentuée, à raison de 0,25 %. Une importante zone vaseuse s'étend de part et d'autre de l'embouchure du fleuve Sénégal. Elle est alimentée par les particules limoneuses transportées par le fleuve jusqu'à la mer où elles sont reprises par les courants qui les entraînent vers le sud-ouest. Les fonds sableux occupent une surface réduite à proximité de la côte.

Variation de la position de l'embouchure

L'embouchure du Sénégal, depuis son origine, s'est déplacée très régulièrement vers le sud, avec par intermittence des replis de 4 à 5 km vers le nord. Au bout d'une période, durant laquelle l'embouchure déplacé d'une distance considérable vers le Sud et que la résistance hydraulique s'est accrue avec l'augmentation de la distance jusqu'à l'embouchure, une nouvelle brèche se produit dans le cordon littoral à 7-8 km au nord. De ce fait, le fleuve passe à travers la Langue de Barbarie, tandis que l'ancienne embouchure se ferme. au contraire. Celle-ci subsiste et peut se rattacher au continent par son extrémité méridionale. Il se forme alors, au sud de la passe, une lagune dont l'étendue est peu à peu réduite par la migration de la nouvelle embouchure.

Tableau 1. Extension de la langue de Barbarie et position de l'embouchure du fleuve depuis 1658 selon les cartes historiques (exprimées en km par rapport à l'île de Saint-Louis).

Année	Km	Année	Km	Année	Km	Année	Km	Année	Km
1658	2,5	1840	20,0	1870	12,0	1913	20,0	1966	20,1
1692	20,0	1843	17,0	1872	12,4	1921	16,0	1967	21,3
1707	4,5	1846	9,0	1872	10,3	1923	15,0	1968	22,2
1717	25,0	1849	16,5	1874	11,5	1928	24,2	1969	22,5
1720	21,0	1849	3,4	1874	13,0	1928	20,8	1969	22,8
1726	10,0	1851	27,5	1882	17,0	1932	23,4	1970	20,0
1727	3,5	1854	4,5	1883	17,4	1936	15,7	1971	24,3
1738	12,0	1855	20,0	1883	14,0	1936	23,9	1973	15,0
1750	22,0	1856	4,5	1884	18,3	1948	16,8	1977	16,3
1780	9,0	1858	3,5	1884	14,4	1950	25,5	1978	19,6
1790	4,5	1859	-0,5	1887	12,1	1955	25,5	1980	21,5
1801	27,5	1860	5,0	1889	15,7	1958	27,0	1981	21,8
1802	18,0	1861	10,9	1894	14,3	1958	27,0	1983	21,0
1802	19,0	1862	8,5	1897	12,8	1959	27,0	1986	23,5
1810	6,0	1863	2,5	1904	18,3	1959	16,5	1989	27,5
1820	7,0	1864	6,0	1905	15,0	1960	16,7	1990	28,0
1824	15,0	1865	8,0	1906	15,7	1960	18,9	2000	30,0
1825	14,4	1866	1,5	1908	16,5	1962	18,0		
1827	30,0	1867	16	1909	20,0	1963	17,7		

De 1850 à 1900, 7 ruptures ont été dénombrées. La plus importante a eu lieu en 1884 provoquant le démantèlement du cordon sableux sur près de 4 km (l'allongement de 24 km entre 1850 et 1851 paraît trop considérable pour être vraisemblable). Depuis 1900, 13 ruptures d'importance inégale se sont produites, la plus récente date de 1973.

Facteurs morphodynamiques

Circulation oceanique et dynamique littorale
Les contours de la côte du delta du Sénégal sont le résultat d'un état d'équilibre entre l'action du fleuve et des courants de houle.

La morphologie de l'avant-côte est marquée de sillons perpendiculaires au rivage, profonds de 0,6 à 1,3 m et larges de 3 à 5 m, qui se succèdent régulièrement sur une zone de 30 à 40 m.

L'onde de marée qui se manifeste sur la côte Saint-Louisienne vient du sud. Elle est de type semi-diurne, mais présente tout de même une composante diurne de l'ordre de 20 cm d'amplitude. Le marnage est microtidal, à peine supérieur à 1 m en niveau et 0,50 m en morte eau, ce qui a pour conséquence un faible développement des estrans.

On observe deux grandes circulations superficielles (Rebert 1983): le courant nord-équatorial qui transporte vers l'Ouest les eaux froides du courant des Canaries et le contre-courant équatorial qui transporte vers l'est les eaux chaudes et salées formées sur la bordure sud du tourbillon nord-atlantique. Pendant la saison des alizés, de novembre à mai, les courants océaniques, au large de Saint-Louis, sont essentiellement tributaires du courant froid des Canaries. Les courants de surface, d'une vitesse de l'ordre d'un nœud, portent au S-W entre Saint-Louis et Dakar (Domain 1977).

Les côtes sénégalaises sont baignées par d'importantes remontées d'eaux profondes ou "up-wellings" qui proviennent de la région des eaux centrales sud-atlantiques (Rebert 1977). Ces courants se manifestent intensément de février à avril entre Saint-Louis et Dakar et dépendent essentiellement de deux facteurs: la morphologie du plateau continental et le régime du vent. BBL-SW (1985) a enregistré, à 9 mètres de profondeur, des vitesses de courant entre 5 et 20 $cm.s^{-1}$ avec des pointes de 42 $cm.s^{-1}$ et avec une direction prédominante du sud (80 % du temps), entre janvier et juin 1983. Dès le début de la saison humide, les masses d'eau méridionales repoussent le front des remontées d'eaux froides. Le courant de surface se propage alors du sud au nord à une vitesse entre 5 et 15 $cm.s^{-1}$, avec des pointes de 30 $cm.s^{-1}$ (BBL-SW 1985).

Deux types de houles, dont les caractéristiques sont différentes selon leur origine et les saisons, se manifestent alternativement dans la région de Saint-Louis:

- La houle de NW prédomine pendant toute la saison sèche d'octobre à juin et a pour origine les tempêtes lointaines de l'Atlantique nord du quadrant NW (N 320° à N 360°). Cette houle atteint la côte sous forme de trains de grande longueur d'onde (en moyenne de 190 à 300 mètres). Son amplitude est généralement plus forte, les valeurs moyennes étant comprises entre 1 et 1,6 m et elle se propage à une vitesse de l'ordre de 22 m/s. La direction moyenne de propagation, pour ces houles d'origine septentrionale, se situe par 22° nord-ouest. A l'approche de la côte de Barbarie, elles subissent une réfraction sur le fond au niveau du plateau continental. Elles perdent alors une grande partie de leur énergie et déferlent plus ou moins obliquement par rapport à la côte. La houle de NW provoque une mobilisation puis un important transport de sable dans le sens nord-sud.
- Les houles du SW se manifestent de juin à octobre et ont pour origine les grands vents d'ouest de l'Atlantique sud. Elles sont liées par leur direction et leur fréquence aux flux de mousson issus de l'Anticyclone de Ste Hélène. Leur amplitude est moins importante avec des valeurs moyennes comprises entre 0,80 et 1,20 m et leur période plus courte (entre 5 et 10 secondes). Leur action est aussi moins marquante. Elles perdent une bonne partie de leur énergie par suite d'une diffraction subie au niveau de la presqu'île du Cap-Vert, véritable écran dont l'abri englobe toute la Langue de

Barbarie. Cette période des houles australes correspond au "démaigrissement" de la plage par suite de la diminution du transport du matériel sableux.

Sur la côte, toutes ces houles, surtout celles du NW, engendrent surtout la dérive littorale. C'est à son existence que l'on attribue la faible élévation du seuil de l'embouchure du fleuve Sénégal. Elle a une direction N-S en face de la Langue de Barbarie ; sa vitesse varie entre 0,13 et 0,57 $m.s^{-1}$. Barusseau *et al.* (1993) indiquent des valeurs mesurées de 0,30 $m.s^{-1}$ qui se corrèlent assez bien avec des valeurs calculées notamment par la formule d'Eagleson, soit 0,5 à 0,2 $m.s^{-1}$ selon Nedeco (1973). Le transport de sable occasionné par cette dérive littorale se produit surtout dans cette zone des brisants à moins de 2,50 m IGN de profondeur (Ostenfel et Jonson 1972). On évalue à environ 600,000 m^3 le volume de sable apporté annuellement à l'extrémité sud de la Langue de Barbarie à partir des relevés topographiques et de son allongement moyen annuel vers le sud.

Dans la vallée estuarienne, l'onde de marée en régime naturel pouvait se propager dans le fleuve jusqu' à 450 km de l'embouchure, par suite de la position du lit en contrebas de l'océan. Dans l'estuaire court actuel, elle est réfléchie à partir de la limite amont, c'est-à-dire le barrage de Diama, une vague est alors propagée vers l'embouchure.

Durant la période de la saison sèche, les vitesses du courant diminuent en fonction de la profondeur et au fur et à mesure que l'on s'éloigne de l'embouchure. A Gandiole, on enregistre des vitesses de près de 50 à 70 $cm.s^{-1}$. On note, pour les durées d'écoulement, un équilibre relatif entre flot et jusant, notamment pour les valeurs fournies par les mesures de surface et de profondeur intermédiaire. Par contre, les vitesses de fond de chenal révèlent un rapport plutôt en faveur du jusant. Les maxima de vitesse du jusant dépassent ceux du flot. Cette primauté du jusant sur le flot est la traduction du comportement normal du fonctionnement estuarien.

Au cours de la saison des hautes eaux, le courant dans l'estuaire se dirige vers l'aval. Le niveau fluvial est élevé et relativement constant. La vitesse maximum du courant, lors de la marée, a été d'environ 70 $cm.s^{-1}$.

L'évolution de la vallée estuarienne est sous la dépendance des apports sédimentaires transportés par les flots annuels de la crue, d'une part, et par les actions de remontée des eaux océaniques dans l'estuaire pendant la saison des basses eaux, d'autre part. Le transport solide du fleuve Sénégal reste relativement faible, mais est surtout variable d'une année à l'autre.

Tableau 2. Bilan des flux particulaires à l'embouchure du fleuve Sénégal

	Concentration (en mg/l)	**Volume écoulé (en m³)**	**Masse (en tonne)**
Diama			
Cycle 89/90	218,32	$8{,}742.10^9$	1 908 716,54
Cycle 90/91	90,49	$6{,}931.10^9$	627 239
Cycle 91/92	187,65	$9{,}073.10^9$	1 702 680
Cycle 92/93	125,28	$7{,}640.10^9$	957 160
Cycle 93/94	190,31	$8{,} 532.10^9$	1,86E+12
Saint-Louis			
Cycle 81/82	251,7	$11{,}384.10^9$	2 865 245
Cycle 82/83	155,5	$7{,}625.10^9$	1 185 903

C'est un fleuve de faible compétence dans son estuaire. Les argiles et les limons transportés en suspension auront donc tendance à se déposer. A l'heure actuelle, le fleuve Sénégal ne joue pas un rôle essentiel dans l'édification de la flèche littorale de la Langue de Barbarie. Il peut, en revanche, contribuer à l'érosion du cordon au cours de la crue.

Observations morphologiques

Les transformations morphologiques de la vallée estuarienne sont également étudiées dans le secteur de référence de l'observatoire de Gandiole (les profils sont numérotés BAR 1F à BAR 16F). Le suivi bi-annuel s'est déroulé par saison et de façon régulière:

- au mois de juin, en période de pré-hivernage, en fin de saison sèche lorsque l'estuaire du Sénégal est soumis aux effets de la marée dynamique et aux flots des eaux océaniques ;
- aux mois d'octobre-novembre, durant la période post-hivernage, lorsque les eaux fluviales d'origine continentale fortement chargées en matières en suspension recouvrent uniformément l'ensemble du bassin-versant du fleuve Sénégal.

Le profil topobathymétrique de la Langue de Barbarie et de son avant-côte comprend trois sections : la plage avec son cordon dunaire, la proche avant-côte et le glacis. Les deux premières sont sujettes à d'importantes variations. Le glacis, quant à lui, présente de modestes transformations qui, en général, ne conduisent qu'à de faibles translations d'ensemble du profil. Le secteur de la base permanente de Gandiole (Figure 2) peut être découpée, d'un côté en deux parties : le nord de la base large (P1-P4) et la base serrée (P5-P13) et, de l'autre, le sud de la base large. La différence entre ces deux domaines est dans la pente moyenne, plus faible au sud qu'au nord (respectivement 0,95 à 1,37 % et 1,71 à 1,94 %).

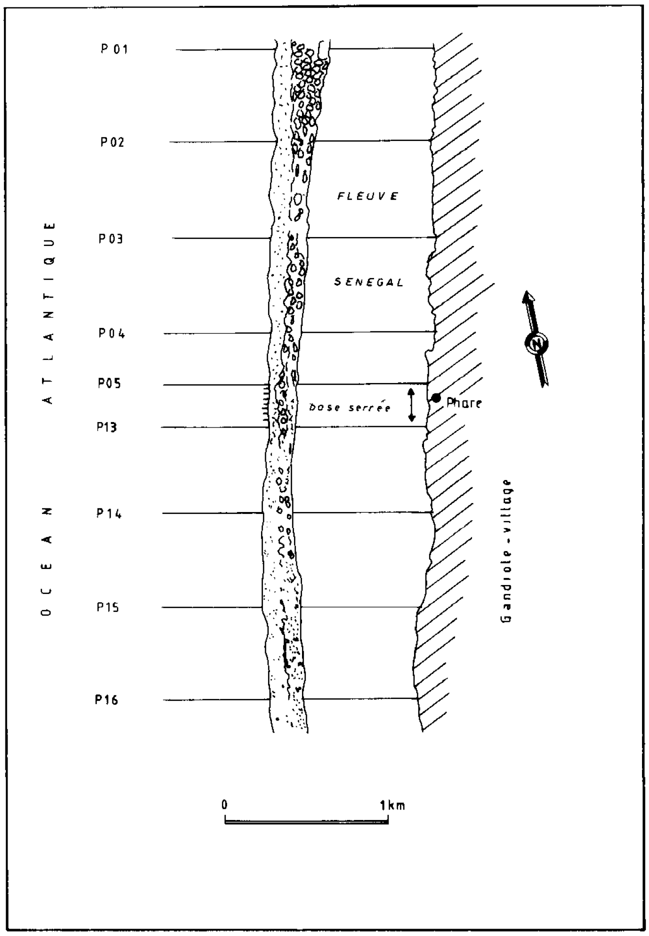


Figure 2. Localisation et disposition de la base d'observations fluvio-marines de Gandiole.

Les observations topobathymetriques dans la vallee estuarienne

Les profils de la base serrée, situés à 50 m de distance les uns des autres, permettent de constituer des ensembles de cartes et de blocs-diagrammes dont on ne présente ici que quelques exemples (Figures 3 et 4). Le chenal présente une section en forme de V aux pentes généralement irrégulières et dissymétriques. Le fond est étroit entre 6 et 8 m de profondeur et localement, des bancs coquilliers altèrent la régularité de l'axe.

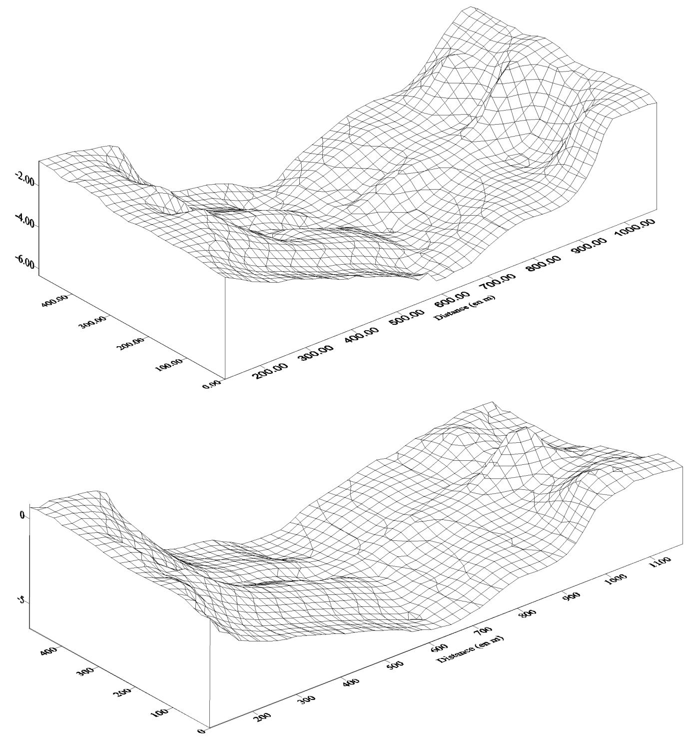


Figure 3. Représentation tridimensionnelle des variations morphologiques de la vallée estuarienne à Gandiole en 1989 et en 1990.

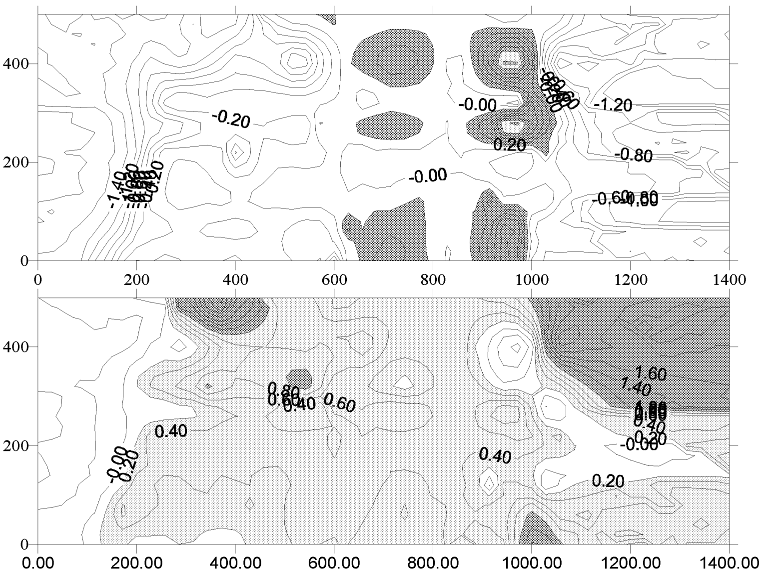


Figure 4. Isovaleurs d'érosion et de sédimentation dans la vallée estuarienne à Gandiole.

L'évolution générale des profils sur la base de Gandiole montre que les versants sont soumis à l'érosion ou à l'accumulation des sédiments en fonction des saisons. La comparaison de la morphologie pré- et post-hivernage montre une régularisation par la crue du fleuve qui se reproduit d'une année sur l'autre (oct.90 - nov.91). Cette modification se surimpose à un processus général d'érosion que l'on perçoit bien quand on observe les cartes de différences (Figure 4). Elles expriment les variations de la profondeur d'une période à l'autre. La grande majorité des différences positives (approfondissement entre la date antérieure et la date postérieure) traduit la dominance d'un régime actuel d'érosion dans le chenal.

Tableau 3. Variation surfacique (en m²) du maître-couple sédimentaire sur les profils de la base de Gandiole.

	juin 89/oct.89	oct.89/oct.90	oct.90/juin 91	juin 91/nov.91
BAR 5F	102	-275	258	-333
BAR 6F	118	-223	69	-121
BAR 7F	131	-618	382	-152
BAR 8F	192	-215	-51	-150
BAR 9F	187	-343	-59	-320
BAR 10F	208	-305	-67	-490
BAR 11F	-143	-642	-69	-317
BAR 12F	56	-1125	279	-131

Sur la base serrée (profils BAR 5F à BAR 13F), les variations surfaciques du maître-couple sédimentaire par profil et par intervalle de temps sont indiqués dans le tableau n° 3 ci-dessus. Sur l'ensemble des 29 mois considérés (de juin 1989 à novembre 1991), la variation moyenne en volume se traduit par un déficit de l'ordre de 400 m³ par mètre linéaire de rive, soit un approfondissement moyen d'une trentaine de centimètres. Les surfaces érodées les plus importantes ont été enregistrées sur les profils BAR 12F soit -1 125 m², et BAR 7F soit -618 m² entre octobre 89 et octobre 90. La surface d'accumulation la plus importante est remarquée sur BAR 10F, soit 208 m² entre juin 89 et octobre 89.
En réalité, cet approfondissement n'est pas régulier dans l'espace. Il est presque systématiquement en rive gauche. En effet, quand l'accumulation domine, elle a lieu plutôt en rive droite (Langue de Barbarie). Les rares fois où des dépôts s'observent sur la rive gauche, ils ont lieu plutôt en bas de versant du chenal qu'en haut.

Cet approfondissement n'est pas non plus uniforme dans le temps et ne caractérise pas systématiquement l'un des deux régimes saisonniers plutôt que l'autre. Ainsi, une majorité de dépôts est observée en hivernage 1989 (+ 100 m³ par mètre de rive) mais aussi en saison sèche 1990/1991 (+ 50 m³ par mètre de rive). Pendant l'hivernage 1991, l'érosion domine (- 200 m³ par mètre de rive). De même, à l'issue d'un cycle annuel complet (octobre 1989-octobre 1990), le déficit atteint 350 m³ par mètre linéaire de rive sur l'ensemble de la base. Ainsi, sur la base de Gandiole, l'accumulation se fait en saison sèche, alors que l'érosion se déroule surtout pendant la saison des hautes eaux.

<u>Les observations topobathymetriques sur le littoral</u>

Caractères généraux
La morphologie générale de la zone marine comprend un secteur fluctuant entre le rivage et les fonds de -3 à -4,5 m. La limite inférieure est marquée par une barre sédimentaire dont le relief, quand il existe, ne dépasse pas un mètre. Cette barre d'avant-côte n'est parfois qu'un épaulement infléchissant la courbe du fond. Parfois, elle disparaît dans le changement de pente qui sépare l'avant-côte du glacis.

La pente moyenne de l'avant-côte, *sensu stricto*, présente des valeurs intermédiaires au niveau de la base serrée de l'observatoire (bornes P5 à P12) par rapport au nord (P1) où la pente est plus forte et au sud (P15 et 16) où elle est plus faible. Sur P10, la valeur la plus faible (juin 1990) atteint 1,13 % tandis que la plus forte (novembre 1991) s'établit à 3,22 %. Sur P16, ces limites sont respectivement 0,78 % (juin 1991) et 3,24 % (juin 1989).

Changements dans la position de la ligne de rivage
Ils sont indiqués dans le tableau n° 4 en rapport avec la position qu'elle occupait en juin 1989. En effet, on constate à l'issue de la saison sèche 1988-1989 un maximum de recul de la côte sur la majorité des profils.

Tableau 4. Variation (en m) de la position de la ligne de rivage par rapport à la situation de juin 1989

PROFIL	1-10-1989	1-06-1990	1-10-1990	1-06-1991	1-11-1991
P1	31	41	123	41	31
P5	41	51	72	72	-31
P6	00	20	41	82	51
P7	62	51	82	82	72
P8	72	41	72	51	62
P9	00	-10	00	00	-10
P10	-1000	31	-10	00	41
P11	-5	123	93	93	113
P12		10	00	-10	-5
P15		41	20		51
P16		00	-31	-82	

D'une manière générale, le rivage a progressé, d'octobre 1990 à juin 1991, dans la partie septentrionale de la zone. Dans la moitié sud de la base serrée, un recul s'instaure au contraire dans cette période mais la tendance s'inverse ensuite de nouveau. L'opposition est nette, à cet égard, entre les profils de P9 et P10. On doit noter également qu'entre octobre 1989 et juin 1990, la croissance de la largeur de la plage subit un ralentissement ou s'inverse même (P9). A l'extrémité méridionale (P15 et P16), l'évolution est également très contrastée. Il y a donc en permanence, sur l'étendue du rivage, des secteurs en érosion quand d'autres s'engraissent.

Modification des profils

Quelques profils topobathymétriques (1 ; 5 ; 6 ; 7 ; 8) sont présentés (Figure 5).

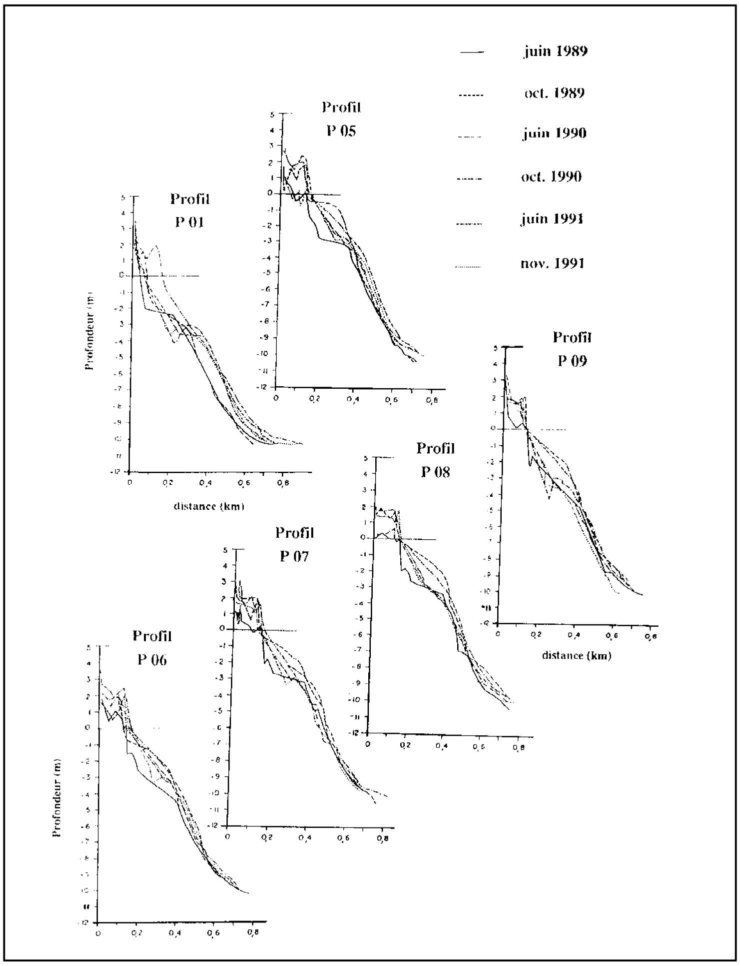


Figure 5. Variations morphologiques du cordon littoral et de l'avant-côte au large de Gandiole, entre 1989 et 1991.

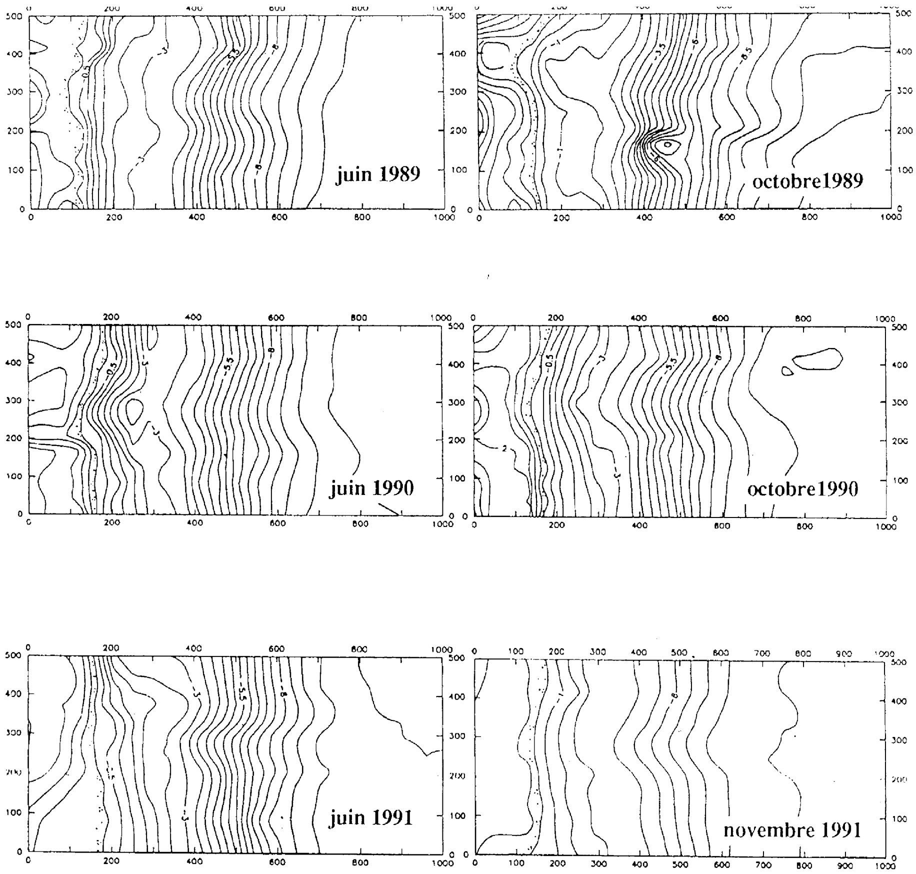
La partie émergée
En juin 1989, la plage est très rétrécie et généralement basse. L'arrière-plage, dans ces conditions, est en pente redressée pour se raccorder au pied du cordon dunaire. Sur certains profils (P5, P7), une bâche d'arrière-berme peut se situer sous le niveau de BM.

Dans la période suivante, la plage se construit. Cette accrétion est en moyenne de 60 m sur la base serrée (nulle sur P9 et maximum 125 m sur P11). La progradation correspond à l'édification d'une plage moyenne s'articulant avec le revers de berme au niveau d'une bâche de HM. Entre juin et octobre 1989, ce processus s'est réalisé en deux phases marquées par la formation de deux bermes successives dont la plus interne est fossilisée par la berme vive observée en octobre.

La berme vive présente une crête située au voisinage de +2 m par rapport aux BM. Elle est précédée par un estran de jet de rive étiré sur une trentaine de mètres et dénivelé d'environ 2 m par la marée. La pente y est généralement forte (de 5 à 7 %).

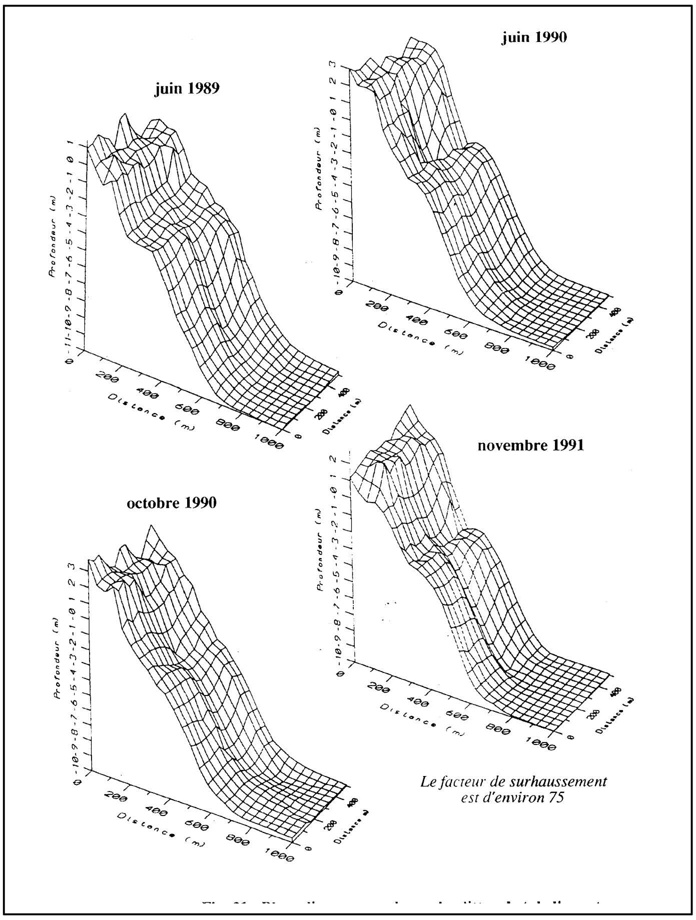
Au cours des trois années étudiées, on ne peut donc pas dire qu'il y ait eu une évolution négative du littoral de la langue de Barbarie dans la région de Gandiole.

Variation cartographique
Elles ne concernent que la base serrée, où les profils sont suffisamment rapprochés les uns des autres. Dans les cartes de la Figure n° 6, la représentation concerne aussi bien la partie émergée (plage et base du cordon dunaire) que la partie sous-aquatique (avant-côte).



Toutes les distances sont en mètres

Figure 6. Cartes topographiques du cordon littoral et de l'avant-côte au large de Gandiole entre 1989 et 1991.



La ligne de rivage est soulignée par un pointillé du côté terre. On note que la basse plage (zone du jet de rive, jusqu'à la crête de berme) ne se distingue pas morphologiquement de la proche avant-côte. L'épaulement où se développe la barre d'avant-côte se matérialise par un desserrement des isobathes dans le domaine -2,50/- 4 m entre deux régions plus pentues.

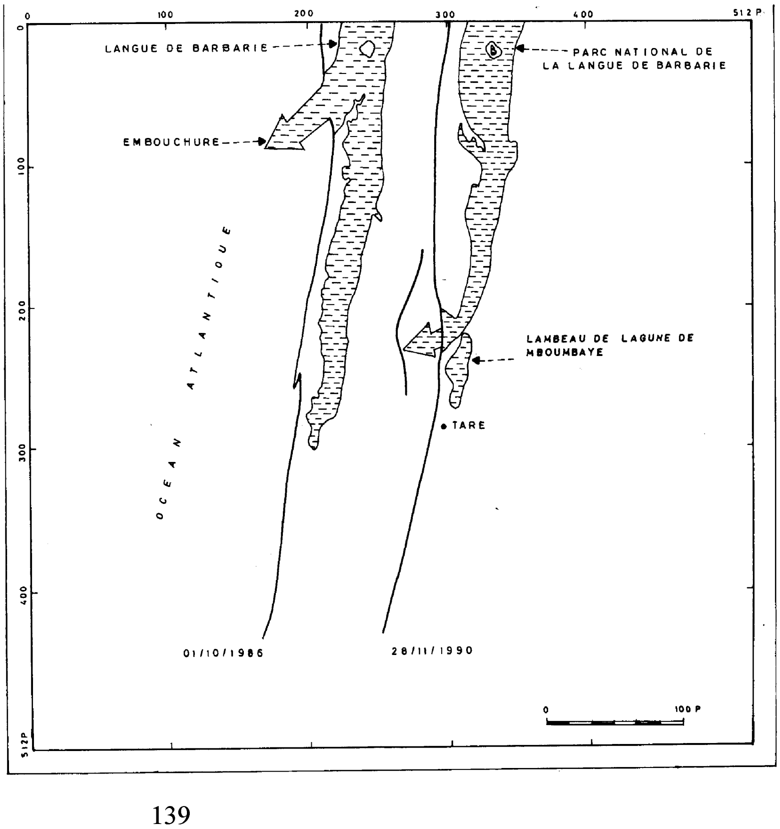
Quelques blocs-diagrammes, présentés à titre d'exemple (Figure 7), montrent plus clairement ces différences. On y voit la relation qui existe entre l'épaulement et la barre d'avant-côte et le passage progressif de l'un à l'autre.

Figure 7. Blocs-diagrammes du cordon littoral et de l'avant-côte au large de Gandiole.

<u>Les modifications morphologiques dans la zone d'embouchure</u>

A la suite de la construction du barrage de Diama, en novembre 1985, sur le cours inférieur du fleuve Sénégal, la partie estuarienne de la vallée, la zone d'embouchure et la zone côtière adjacente ont connu des transformations importantes, illustrées par la comparaison des cartes issues d'images satellitaires de 1986 et de 1990 (Figure 8).

Figure 8. Evolution de la position de l'embouchure du fleuve Sénégal d'octobre 1986 à novembre 1990.



Nous remarquons :

- une extension vers le sud de la Langue de Barbarie qui, mesurée sur les deux images s'est allongée de près de 4 000 m;
- un élargissement et un épaississement du segment distal de la Langue de Barbarie qui fonctionne comme une zone d'accumulation des sédiments;
- un raccourcissement de la flèche sableuse de la lagune de Mboumbaye, dont la portion terminale est complètement isolée du système estuarien.

Les variations morphologiques sont étroitement liées à l'hydrodynamisme estuarien, contrôlé depuis 1985 par le fonctionnement du barrage de Diama.

L'évolution actuelle de la Langue de Barbarie est plutôt marquée depuis le début des années 1980, par le rétrécissement du rivage externe et aussi par l'allongement de sa pointe méridionale. Ceci est confirmé par l'ensablement partiel ou l'exhaussement du mur de protection, encore présent sur la plage à Saint-Louis. L'érosion est très marquée avec un recul de la haute plage et du sillon oblique de 12,5 m au droit de Guet-Ndar et de 2,5 à 5 m ailleurs au cours de la saison sèche (Ba et Sy 1987).

Conclusion

La position de l'embouchure du fleuve Sénégal est naturellement évolutive, mais cette instabilité demeure aujourd'hui limitée depuis l'avènement des barrages. Les remaniements sont désormais tributaires des apports continentaux piégés par le barrage de Diama qui opère une importante rétention sédimentaire. La zone littorale de la Langue de Barbarie, siège de la pérégrination de l'embouchure du fleuve, a été étudiée au point de vue morphologique au nord de la localisation actuelle de la passe. La partie sud de la flèche paraît en état d'accrétion (pente plus faible de l'avant-côte et sensibilité nulle à l'érosion), tandis qu'au niveau de la base serrée (face à Gandiole), la partie basse du profil transversal sous-marin montre un certain déséquilibre. Celui-ci pourrait entraîner l'apparition de conditions favorables à la formation d'une embouchure plus septentrionale que l'actuelle. La prévision d'une ouverture de l'embouchure en position plus septentrionale doit être considérée avec prudence.

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4.9 Catchment activities in the Volta River Basin and their impact on the Gulf of Guinea

Chris Gordon

Extended abstract

The Volta River basin, with an area of almost 400,000 km^2, is the ninth largest river/lake basin in sub-Saharan Africa. It covers six nations (Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali and Togo) and contains some of the sub-region's most important environmental, social, land and economic resources. The basin provides water for hydroelectric power generation, domestic supplies, irrigation, livestock watering, transportation, and fisheries.

The primary environmental problems facing the Volta River basin stem from poverty and lack of equity in the distribution of and in access to resources. Throughout the basin, chronic poverty is the main cause and consequence of environmental degradation, which continues to undermine sustainable economic development. This is because poverty drives populations into the unsustainable use of natural resources and onto marginal lands. According to UNDP/World Bank classification these countries are amongst the poorest in Africa with high population growth rates and low *per capita* incomes (Table 1).

Table 1. National statistics on population growth rates, income and debt of countries sharing the Volta River basin.

Country	Population Growth Rate (% per year; 1998 estimate)	GNP *per capita*/yr. (US$ 1997 estimate)	Debt as % of GNP (1995 estimate)
Benin	3.31	380	75
Burkina Faso	2.72	250	65
Côte d' Ivoire	2.21	710	161
Ghana	2.13	390	85
Mali	3.24	260	121
Togo	3.52	340	107

The construction of various large- and small-scale impoundments in all the riverine nations has caused significant changes to the environment and consequently to the distribution and livelihoods of people both upstream and downstream of the dams. These changes extend to the coastal wetlands associated with the Volta Estuary. In addition, the coastlines of some of the riparian countries have experienced coastal erosion as the possible consequence of reduction in sediment flux.

The largest of these impoundments, the Volta and Kpong dams in Ghana, are the major sources of electricity for Ghana (currently providing almost 95% of total consumption), with over 10% of total production (≅ 70 MW) exported to the neighbouring countries of Togo and Benin. The decline in the lake's water level due to reduced inflows caused by drought and the unsustainable rate of abstraction has resulted in episodic and catastrophic energy shortfalls affecting Benin, Ghana and Togo (as an indication, over the past decade the reservoir has been operating below its minimum design depth of 75.6 m). As a further indication of the overall water scarcity in the area concerned, according to recent expert estimates[1], three of the six riparian countries, Burkina Faso, Ghana and Togo are expected to face water stress (i.e. water availability of between 500 and 2000 m^3/person/year) by the year 2025. The problem of water availability caused by population increase and life style expectation/changes is compounded by short-term climatic variability, which is manifested in the form of Sahalian drought. Linked to this issue is the overarching problem of increased evapo-transpiration, which further reduces water availability in dry years.

[1] Gardner-Outlaw, T. and Engleman, R. (1997) Sustaining Water, Easing Scarcity: a Second Update. Population Action International, Washington, 19 pages.

Apart from the fundamental issue of the basic lack of water, whereby the majority of inhabitants of the Volta River basin currently do not have access to safe and secure water supply, the major environmental concerns of the Volta River basin include:

- Degradation of the quality of trans-boundary water resources through the introduction of toxic chemicals, nutrients, pathogens, oxygen-demanding wastes, sediment and solid waste.
- Introduction of non-indigenous species causing the disruption of aquatic ecosystems as well as health threats through the creation of habitats for vectors and hosts of water-related diseases.
- Physical habitat degradation of lakes and water courses, wetlands, mangroves and estuaries as a result of land conversion, dredging, coastal construction and irrigation, and changes in water flow regimes downstream.
- Excessive exploitation of living and non-living resources, including over-fishing and water withdrawal, due to inadequate management and control measures.
- Soil erosion caused by factors such as deforestation, bush-fires and overgrazing, which leads to decreased water quality such as increases in turbidity and decreases in transparency, and in the long run loss of habitat by the siltation of water bodies.
- Explosive growth of waterweeds, one manifestation of eutrophication, which results from the over- and improper use of chemical fertilizers as well as the inadequate treatment and disposal of domestic and animal waste.

Several of the riparian nations have already carried out water resource management studies and/or environmental strategies and action plans. These activities, aimed at identifying and analysing water resources and environmental degradation at the national level, need to be revisited at the river catchment level.

Due to the large degree of interdependency between the riparian nations, up-stream/down-stream actions and impacts are very much linked. Though Togo and Benin are upstream from Ghana, they suffer the effects of lack of water in Ghana through the link via power generation and supply. Due to long-shore drift and the prevailing direction of coastal currents (west to east), activities in the hinterlands of Togo and Benin also affect their coasts via the discharge and transport of material through the Volta estuary in Ghana. Sahalian countries have significant nomadic populations who move north-south crossing national boundaries in search of fodder and water for their livestock. The identified environmental problems listed in Table 2 vary in intensity both within and between countries. It is this intra- and inter-national variation that is one reason for adopting a basin-wide approach to problem solving, with each nation providing and sharing information and knowledge with other riparian countries.

Table 2. Key environmental problems and their causes in the Volta Basin.

Problem	***Cause***
Upstream	
Diminishing water resources	Increased demands and increased pollution (which reduce availability or increases the cost of the available polluted waters; altered hydrology from changes in land use which affect runoff/infiltration.
Hydrological changes	Changes in land use which affects runoff and infiltration patterns; sedimentation of canals/rivers which reduces hydraulic efficiency.
Soil erosion	Deforestation; bush-fires; overgrazing; nomadism and human migration; uncontrolled human settlements along river banks the eroded soils resulting in decreased water quality.
Downstream	
Pollution	Dumping of human, domestic and industrial waste into water courses; leaching of agro-chemicals into rivers; salt water intrusion; oil spillage; waste from mining activities; use of agro-chemicals in fishing.
Coastal erosion	The inadequate flow of sediments to the coast due to physical development within the basin.
Coastal pollution	Transport of pollutants to the coastal zone.
Flooding	Uncontrolled spilling from reservoirs; inadequacy/lack of early-warning systems; intense precipitation at short intervals; loss of wetlands.
Basin -wide	
Loss of biodiversity	Deforestation; pollution; over-exploitation of natural resources by humans and their livestock (overgrazing); changes in flow regimes downstream of dams; inundation of reservoir areas; dams as barriers.
Aquatic weeds	The introduction (deliberate in the case of florists, accidental in the case of fishermen and others) of exotic aquatic plants; the problem is exacerbated by increased nutrient availability, which promotes explosive growth, from both organic and inorganic sources.
Water-borne diseases	Creation of dams or impoundments; changes in flow regimes; contamination of water bodies with human waste and pollution; infestation of water bodies with aquatic weeds, habitat for hosts and vectors.
Inadequate / no information dissemination mechanisms	Inadequate resources (financial/human) for information gathering; absence of a regional mechanism for gathering information from member countries.
Inadequate institutional and legal framework for basin management	Lack of an enabling political environment.

4.10 Effets du barrage de Nangbéto sur l'évolution du trait de côte: une analyse prévisionnelle sédimentologique

Adoté Blivi

Résumé :
En vue d'optimiser le rendement hydro-électrique, un second barrage est en projet, à 100 km en aval du barrage de Nangbéto sur le fleuve Mono au Togo. Celui-ci a été mis en service en 1987 à des fins de production d'énergie électrique et de mise en valeur hydro-agricole de la basse vallée. Les travaux de topographie, de bathymétrie et de sédimentologie successifs relatifs au barrage de Nangbéto et à la pré-étude d'impact du second barrage à Adjarala ont pour objectif la maîtrise du transport solide dans la vallée et vers la mer, ainsi que des comportements du trait de côte.

Les résultats de terrain montrent que les effets morpho-sédimentaires consécutifs à la mise en service du barrage de Nangbéto ne se sont pas encore répercutés dans la zone côtière.

Cette contribution tente de montrer particulièrement l'impact qu'auraient les effets sédimentologiques sur l'évolution du trait de côte entre le Togo et le Bénin.

Mots clés : Mono, hydro-électrique, topographie, bathymétrie, sédimentologie.

Abstract:
In order to optimize the hydro-electric output on the Mono River in Togo, a second dam is in project 100 km downstream from the Nangbeto dam, which was brought onstream in 1987 for the purposes of producing electric energy and of exploiting hydro-agricultural potentialities of the lower valley. The successive topographic, bathymetric and sedimentologic works pertaining to the Nangbeto dam and to the pre-study of the impact of the second dam at Adjarala aim at mastering the solid drain in the valley and towards the sea, as well as the behaviour of the coastline.

The field results show that the morpho-sedimentary effects resulting from the bringing on line of the Nangbeto dam have not yet affected the coastal zone.

This paper attempts to show the impact that the sedimentologic effects would have on the evolution of the coastline between Togo and Benin.

Key words: Mono, hydro-electric, topography, bathymetry, sedimentology.

Introduction

Le Mono est un fleuve dont le cours inférieur est partagé entre le Togo et le Bénin (Figure 1). La réduction de la dépendance énergétique et surtout la croissance des besoins en énergie électrique pour les populations des deux pays ont motivé un programme régional de réalisation de barrages hydro-électriques.

Le premier barrage, mis en service en 1987, est localisé à 35 km à l'est d'Atakpamé sur un site structural de collines résiduelles de 147 m et de 167 m d'altitude encadrant la vallée du fleuve dont le talweg est à 110 m de profondeur. Le site est favorable aux chutes d'eau nécessaires pour le fonctionnement de l'ouvrage et à un lac de retenue d'une superficie de 180 km^2. Les effets à l'aval de l'ouvrage se manifestent dans le bassin sédimentaire par l'érosion des berges suivie de recoupements de méandres, l'érosion du fond avec transport du débit solide, les débordements des eaux sur la plaine alluviale. Les eaux provoquent des inondations et la dulcification des eaux marines du système lagunaire (Rossi et Blivi 1995; Gnongbo 1998). Le second barrage, en phase de projet, est situé à 100 km en aval de Nangbéto et a fait l'objet de plusieurs études d'impacts dont celles relatives à l'hydrologie et à la sédimentologie (Coyne et Bellier 1992).

De l'analyse des mesures in situ, il se dégage déjà avec le barrage de Nangbéto un nouveau régime hydrologique en concordance avec la gestion des eaux de lâchers. Cette situation sera toujours mise en évidence avec le barrage d'Adjarala et sera couplée avec l'élévation du niveau de l'eau dans le fleuve et dans la lagune. Plusieurs séquences sédimentologiques, par le jeu du transport vers l'aval, vont se développer graduellement dans le temps à partir de la retenue, le long du fleuve, près de l'embouchure et se manifesteront également par les variations du trait de côte.

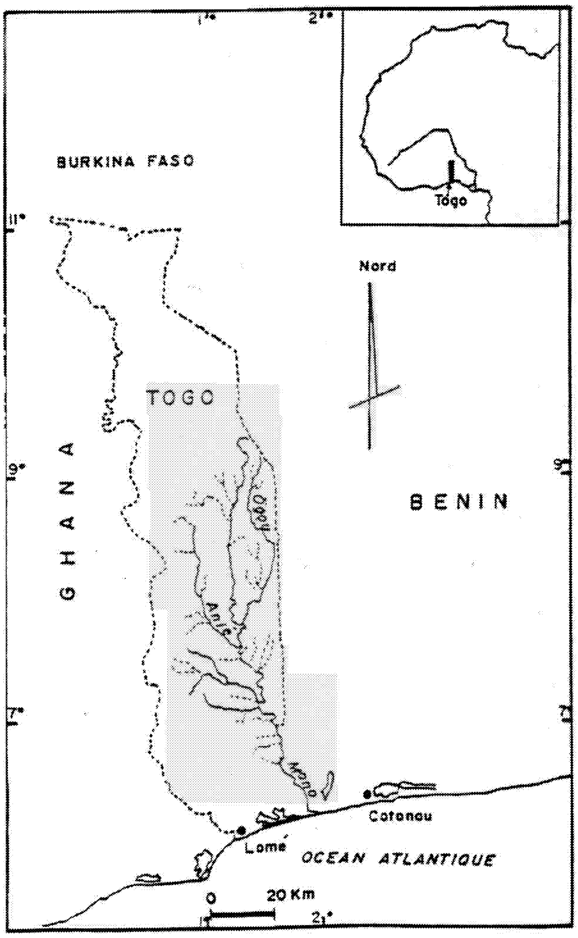


Figure 1. Cours inférieur du Mono entre le Togo et le Bénin.

Cadre géographique du fleuve Mono

Le Mono draine, avec ses principaux affluents Anié, Amou et Kra Ogou, un bassin versant d'une surface de 24 000 km^2 entre 9°20'N et 6°16'N de latitude et 0°41'E et 1°51'E de longitude (Figure 2). Le relief, d'altitude comprise entre 0 et + 400 m du sud au nord, bénéficie de deux types de climat. Il est établi sur des structures géologiques assez bien différenciées auxquelles correspondent des formations végétales variées de forêts semi-décidues et de savanes guinéennes.

Les données climatiques et hydrologiques

Le 8ème parallèle sépare le bassin du fleuve Mono en deux zones climatiques: au nord, un climat tropical à saisons sèches et pluvieuses avec un total pluviométrique variant entre 1000 et 1300 mm/an et, au sud, un climat de type subéquatorial à quatre saisons dont deux pluvieuses et deux sèches alternées, avec un total de 900 à 1100 mm/an. Sa zone côtière, qui connaît une anomalie climatique, reçoit de 800 à 900 mm/an. Le régime thermique moyen présente une dynamique monotone qui varie entre 24 et 26°C sur l'ensemble du bassin. Les mois de forte chaleur sont février et mars avec des températures de l'ordre de 30°C (Figure 3). Cette situation climatique assez fluctuante le long du bassin, avec des averses de forte intensité à l'origine de quelques rares crues brutales, a de sérieuses répercutions sur le comportement hydrologique et sur les débits du fleuve.

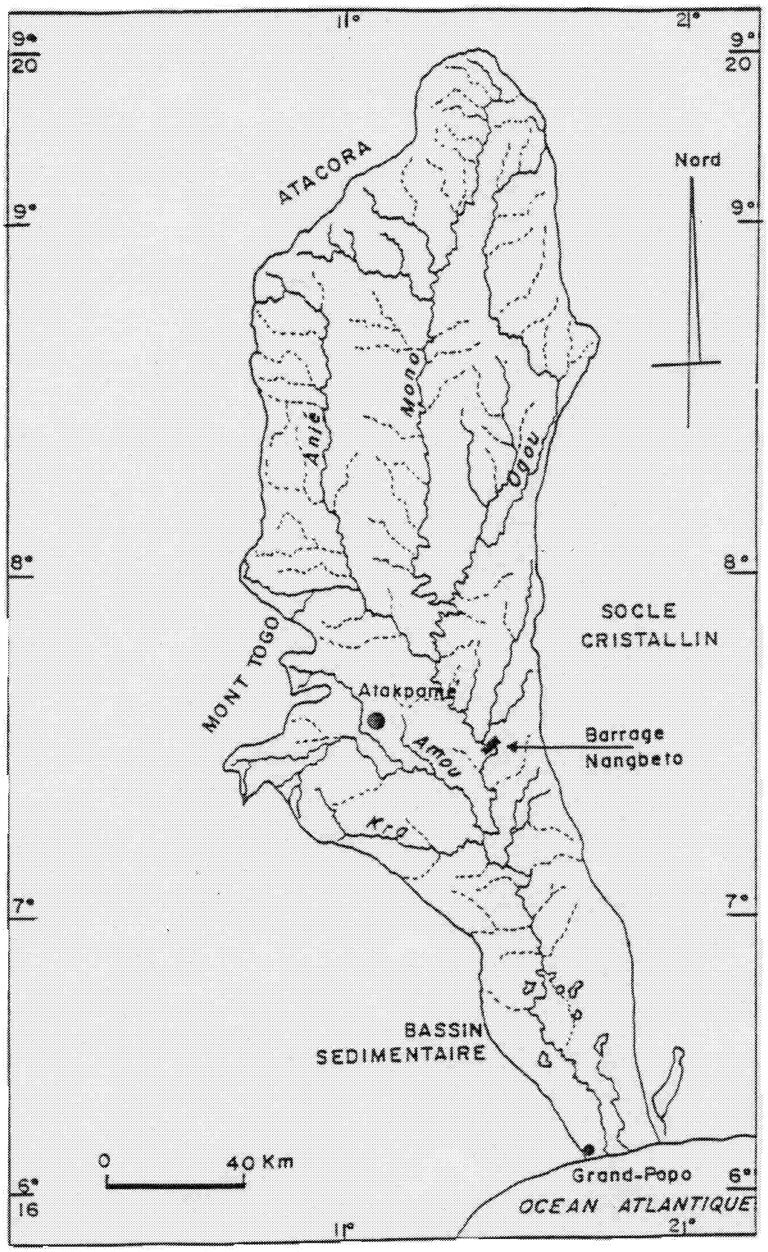
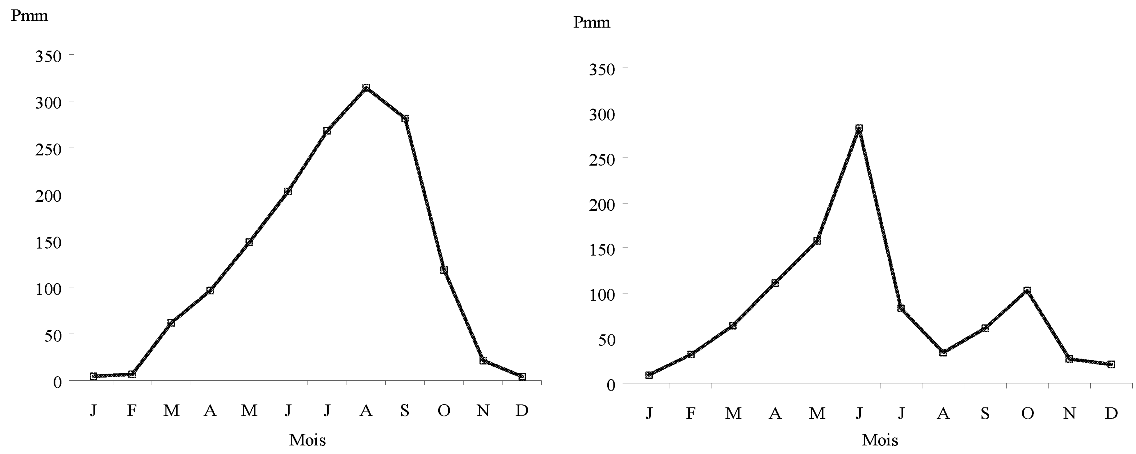


Figure 2. Le bassin hydrographique du Mono.

Les données hydrologiques du fleuve Mono a été complétées par les récents travaux de Klassou (1996) et Gnongbo (1998). Le Mono connaît les forts débits pendant les mois de septembre et octobre, pouvant atteindre 680 à 700 m^3/s pour une crue d'année médiane. Les crues décennales portent les débits à 850 m^3/s, soit un écoulement d'eau de 40 $l/s/km^2$ à Athiémé. Les étiages, d'une durée de 6 mois, de novembre à avril, présentent des débits à 0,8 m^3/s. Avec le barrage de Nangbéto, les étiages nuls ne sont plus observés puisque le régime hydrologique a changé, portant le débit minimum à 40 m^3/s pendant toute l'année (Figure 4). C'est pendant la période de fort débit, correspondant à une forte énergie d'écoulement que s'effectuent les processus de transport (mise en suspension et charriage) des sédiments.



Aledjo   Grand Popo

Figure 3. Courbes pluviométriques des stations d'Alédjo et de Grand Popo.

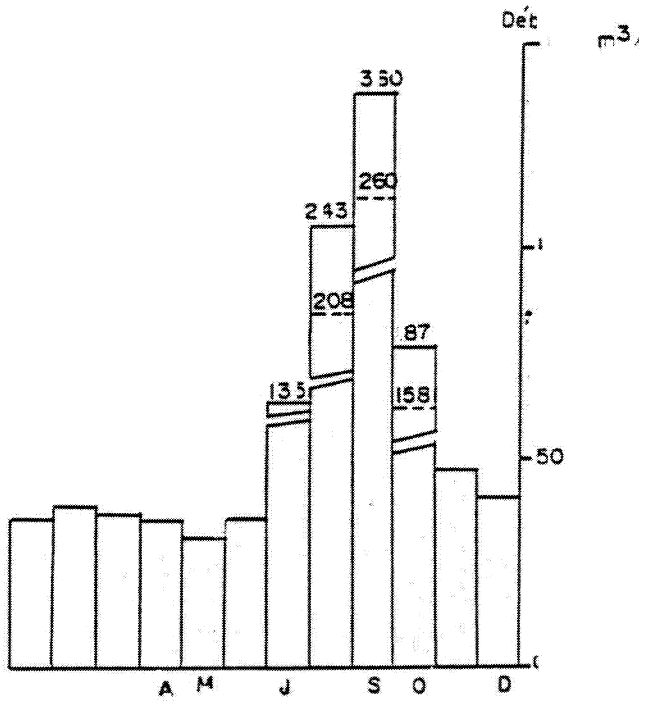


Figure 4. Régime actuel hydrologique du Mono après le barrage de Nangbéto (après Blivi 1998)**.**

Les données géomorphologiques

Dans l'ensemble, le relief se caractérise par une topographie peu complexe, bien différenciée. Il est établi dans un bassin sédimentaire côtier de plaine littorale et de plateau de "Terre de Barre", sur une surface de socle cristallin d'érosion, d'aplanissement et dans une structure de monts constitués de quartzis et de micaschistes dont les altitudes varient entre 400 et 900 m. Cette série morphologique successive montre une disposition structurale le long du fleuve Mono, correspondant aux accidents séparant de longues surfaces subplanes dominées par des séries d'inselbergs granitiques (Rossi et Antoine 1990). Des biefs et des rapides, dont ceux de l'Adjarala, avec une pente de 5% où est prévu le deuxième barrage marquent l'action différentielle de l'érosion sur un substrat lithologique bien varié. Le bassin inférieur, partagé par le Togo et le Bénin, se trouve dans les formations sédimentaires argilo-sableuses avec des pentes médiocres (0,4 à 1,2 m/km).

La configuration topographique donne des valeurs de pente générale assez faible tout au long du fleuve, soit 1% en moyenne, .ce qui va influer sur la vitesse d'écoulement et sur le rapport débit/charge. Les réponses morpho-sédimentaires sont sensibles aussi bien dans la géométrie que dans la quantité de matériaux charriés (Rossi et Blivi 1995; Klassou 1996). L'érosion spécifique moyenne est de 60t/km^2/an déterminant un apport solide moyen annuel estimé à 950 000 t à Nangbéto. La charge solide est composée de silts, de sables et de graviers dont les diamètres diminuent de l'amont vers l'aval.

Le transport solide du Mono

La fourniture sédimentaire serait de l'ordre de 100 000 m^3 de sable par an à la côte. La mise en service du barrage a déclenché une réduction progressive des apports solides du fleuve à la zone côtière.

Les données sédimentologiques
Pendant les campagnes de mesures de 1986 et 1991, les cartes topographiques au 1/50 000^{e}, les levés topomorphologiques, les reconnaissances et la photointerprétation ont permis d'avoir une approche convenable du phénomène de crue dans la vallée (Université du Bénin, 1991). Le profil en long permet de distinguer des affleurements rocheux de Nangbéto jusqu'à la zone de rapides, puis à l'entrée de la plaine et dans toute la plaine alluviale. Ces secteurs ont été levés et font apparaître des profils monotones et classiques avec des bords élevés représentant des bourrelets de berge.

Les analyses granulométriques, faites à partir de plusieurs centaines d'échantillons, montrent des pourcentages élevés de sable et de silt avec des diamètres caractéristiques de D50-D75 et D90 des sables. Les résultats montrent que tous les échantillons contenant au moins 10 % de silt sont situés en berge, sur les bourrelets ou sur la plaine inondable. Le pourcentage de silt de ces échantillons est de l'ordre de 10 à 95 %, avec une très forte proportion en vallée inondée et une proportion de l'ordre de 30 à 60 % sur les bourrelets de berge. Par contre, presque tous les échantillons de fond ou de plage ne contiennent pas de sédiments fins. C'est ainsi que certains échantillons à forte teneur en silt prélevés dans le lit mineur correspondent tous à des fonds de mares ou à des lits de crue secs au moment des prélèvements. Les autres échantillons, prélevés sur le lit mineur sont formés de sable dont les granulométries décroissent légèrement de l'amont vers l' aval (Figure 5). Cette décroissance, assez légère, est en rapport avec les pentes caractéristiques du lit par grands secteurs géographiques (Tableau 1).

Tableau 1. Diamètres du matériau, pentes et hauteurs de berges.

	PK	Pente m/km	Diamètre (m)	Hauteur (m)
Amont de Nangbéto	225 - 300	0,45	1,5	5
Aval de Nangbéto	145 - 225	0,85	1,3	5
Rapides	130 - 145	5,00	1,2	3
Plaine	40 - 130	0,20	1,0	7
Transition	25 - 40	0,10	0,6	5
Estuaire	0 - 25	0,05	0,3	2,5

Tous les sédiments sableux sont transportés en suspension dans les mêmes conditions qu'à l'amont du barrage. Le diamètre moyen des sédiments du secteur estuarien correspond très sensiblement à celui du matériau du cordon, d'après les précèdentes observations et mesures que nous avons effectuées (Université du Bénin 1991).

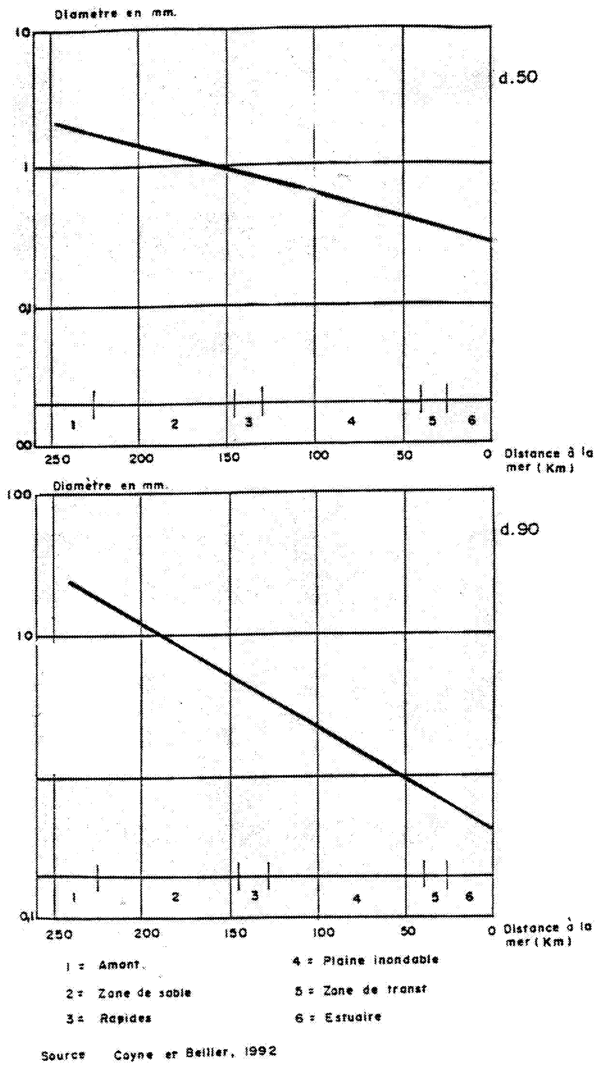


Figure 5. Echelonnement des diamètres de sable le long du fleuve Mono (après Blivi 1998).

Les modalités du transport en aval de l'ouvrage

La capacité de transport solide du fleuve Mono en aval de l'ouvrage est en rapport avec la géométrie du lit, notamment la largeur du lit mobile, la hauteur d'eau, le diamètre du sable, la pente. Dans cette approche, quelques paramètres interviennent dans le calcul du transport : le coefficient de rugosité du fond, le coefficient de rugosité du grain, le débit solide ou la capacité de transport correspondant à la hauteur d'eau et le débit liquide total. Les capacités de transport solide le long du fleuve sont donc fonction des grands secteurs géographiques (amont du barrage, aval du barrage, zone des rapides, aval des rapides et débordement et cours de la plaine) dont les caractéristiques structurales et topographiques diffèrent. La mise en mouvement des matériaux sur le fond est déterminée par un certain débit : le mouvement des sables dans le lit s'effectue dès que le débit atteint 5 à 6 m^3/s dans le secteur situé entre l'aval des rapides/débordement et le cours de la plaine. Dans le secteur aval du cours de la plaine, le débit doit varier de 10 à 15 m^3/s. Les secteurs n'ont pas ainsi les mêmes capacités de transport.

Les volumes de sédiments écoulés enamont comme en aval sont de $1{,}8.10^6$ m^3/an en moyenne, avec des durées de transit très différentes. Le mécanisme du transport est simple: les crues d'amont apportent le sédiment qui se dépose à l'entrée de la plaine qui est ensuite repris hors période de crue par les débits moyens. D'après les anciennes mesures de l'ORSTOM, les apports solides sont estimés à 950 000 t/an. Par le jeu de transport vers l'estuaire, 100 000 m^3/an de sable sont déversés dans la mer. La capacité de transport solide à l'aval de Nangbéto avoisine théoriquement 1 800 000 m^3. Toute la charge solide en provenance du bassin est, en l'état naturel des choses, évacuée jusqu'à l'estuaire du Mono.

Impacts des ouvrages sur le transport solide

Le barrage de Nangbéto a apporté des modifications sur la courbe des débits classés journaliers (renforcement des étiages, écrêtement des hautes eaux) sans traduire une variation significative de la capacité de transport solide. Le transport s'opère au détriment du fond et des rives sur la partie aval. Comme le volume de sable déposé à l'aval de l'ouvrage est évalué à 8 millions de tonnes et que dans la retenue, il est de l'ordre de 100 à 150,000 tonnes de sable, le stock disponible représente de 40 à 60 ans d'apports solides peu modifiés à l'entrée de la zone estuarienne.

L'effet du projet de barrage d'Adjarala, combiné avec celui de Nangbéto, provoquerait une baisse assez sensible des apports même si le volume disponible entre Nangbéto et Adjarala ne représente qu'une fraction minime du volume sédimentaire total en transit. Le barrage d'Adjarala, localisé à l'entrée de la basse vallée entraînera le piégeage de l'apport sédimentaire des affluents compris entre les deux ouvrages, soit 150 à 200 000 tonnes de sédiments, créant ainsi un déficit d'apport à la côte de l'ordre de 20 000 m^3 de sable. L'exploitation du barrage d'Adjarala conduira à une diminution substantielle de la durée du stock sédimentaire à l'aval de l'ouvrage, durée qui ne devrait pas dépasser 30 ans. Au fur et à mesure de la liquidation des sédiments, des érosions de berges apparaîtront nettement et occasionneront graduellement des impacts sur la côte.

Analyse prévisionnelle sédimentologique et évolution du trait de côte

Depuis quelques décennies, la côte du golfe de Guinée est soumise à une violente érosion due à des causes naturelles mais surtout anthropiques (Blivi 1993b; Anthony et Blivi 1999). Les jetées des ports de Lomé et de Cotonou interceptent le volume sédimentaire en transit et provoquent une perturbation des conditions hydrosédimentaires le long de la côte. Ce phénomène se traduit par une plage en progradation et par une plage en érosion. Ces états de plage se caractérisent par une progression successive de trait de côte dans le temps et dans l'espace (CEE 1989; Rossi 1989). Des reculs de l'ordre de 10 m/an sont observés sur 4 à 5 km de côte à l'est du système d'ouvrages maritimes de Cotonou (Figure 6). Par ailleurs, un decul de 5 m/an en moyenne est signalé sur environ 35 km de côte au Togo (Blivi 1993). L'impact du barrage sur les fleuves se remarque à travers la baisse du flux sédimentaire en zone côtière. Il se caractérise par le remodelage et le recul des plages, la fragilité des flèches sableuses (barrières) qui sont déplacées vers la lagune par le jeu des marées.

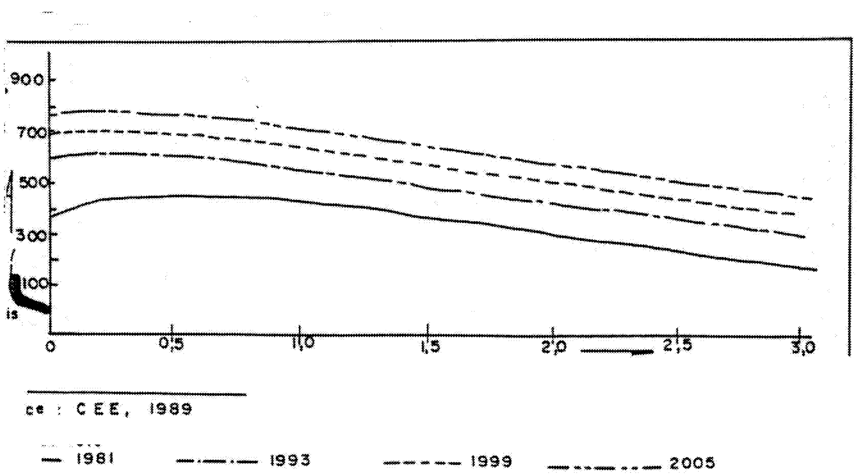


Figure 6. Recul du trait de côte (10m/an) à l'Est de l'épi courbe à Cotonou et prévision à 2005. (après Blivi 1998).

Dans ces contextes, l'évolution du trait de côte fait l'objet d'une part d'un programme de suivi par levés topographiques de plage pour déterminer la vitesse de recul et les différentes sensibilités de côtes à l'érosion et, d'autre part, d'analyse du bilan sédimentaire fluvial et marin en transit.

La prévision sédimentologique
Dans la mesure où il y a localisation des points d'attaque à la côte et connaissance de la vitesse de déplacement des zones d'érosion, il est possible de prédire à l'avance dans le temps et l'espace les secteurs menacés par l'érosion, d'où la notion de sédimentologie prévisionnelle (Lorin 1984).

L'analyse prévisionnelle se dégage de l'étude du modèle mathématique de l'évolution du littoral entre la frontière togolaise et la région de Ouidah et, par ailleurs, de l'exploitation de deux modèles réduits sédimentologiques qui concernaient la protection de la côte togolaise. Ces modèles ont permis de définir, dans le temps, l'évolution des apports du Mono dans la zone côtière et de simuler la position du trait de côte par rapport à l'érosion et à la sédimentation en fonction de la variation du volume sédimentaire fluvial. L'échelle temporelle considérée est de 25 à 50 ans.

Le modèle est appliqué à une longueur de côte de 50 km à partir de la frontière en considérant que la côte est rectiligne d'après les données physiques issues de documents cartographiques. Dans la réalité, au niveau de l'embouchure, les jeux du mécanisme hydraulique du Mono montrent de faibles variations du trait de côte (avancée et recul) et des déplacements du débouché vers l'Est selon le rapport débit/charge et les flux hydrodynamiques marins. Ces effets mineures sur le trait de côte justifient le fait que le modèle ait pris en compte une côte rectiligne pour permettre l'analyse.

Avec la mise en service du barrage de Nangbéto depuis 1987, les apports sableux dans la zone côtière initialement de 100 000 m^3/an devraient décroître jusqu'à devenir presque nuls (c'est à dire un apport sableux inefficace pour la dynamique sédimentaire côtière) entre 2012 et 2037. Quatre scénarios ont été testés pour simuler la baisse du flux sédimentaire à partir de l'apport naturel initial du Mono : 75 000 m^3/an ; 50 000 m^3/an ; 25 000 m^3/an et 0 m^3/an. Ces hypothèses permettent de définir différentes situations, comme la migration de l'embouchure vers l'Est. Dans chaque situation, la simulation de la migration a été évaluée à 1 km tous les 5 ans. Parmi ces tests, la situation vraisemblable à compter de 2012 est celle d'une décroissance des apports de 75 000 à 25 000 m^3/an. Cependant, l'analyse prévisionnelle pour chaque situation a été faite par tranche de 5, 10, 15, 20 et 25 ans sur un segment de côte de 50 km (l'embouchure du Mono se situant au PK 33) pour tenir compte de l'importance et de l'influence théorique des apports du Mono. Ceux-ci se caractérisent par des déplacements différentiels du littoral au cours du temps en différents points de la côte.

L'évolution du trait de côte.
A partir de ces situations assez réalistes, une simulation de l'évolution du trait de côte a été effectuée. L'impact direct de la baisse du volume sédimentaire a été mis en évidence sur environ 20 km de part et d'autre de l'embouchure avec des séquences de progradation et de recul. Ces évolutions constatées attestent le comportement hydraulique du fleuve et le volume de sables déversé en mer.

L'érosion côtière autour de l'embouchure rendra très fragile le cordon barrière aura à peine une dizaine de mètres de largeur à partir de 2012. Cependant, son effet ne sera pas ressenti sur la plage de Grand-Popo qui bénéficiera toujours des apports de sables en provenance de l'ouest, notamment de la côte togolaise en érosion. Compte tenu d'une réduction de 100 000 à 25 000 m^3/an, le trait de côte reculera de 10 à 12 m. Dans la situation d'une baisse totale des apports, c'est à dire de 100 000 m^3/an à 0, le recul atteindra au maximum 20 m au débouché du Mono avec des basculements successifs du cordon barrière sur une dizaine de kilomètres de longueur et des ruptures en plusieurs points très fragiles (Figure 7). Ces évolutions du trait de côte sont très significatives, en ce sens que l'impact du barrage sur le trait de côte est quantitativement confirmé et ce, jusqu'en 2012, où il sera observé et bien mesuré. Dans tous les cas de figure, pendant la période de 25 ans après la construction du premier barrage en 1987, l'effet de l'érosion à l'embouchure due à la réduction sédimentaire restera faible avec des avancées et des reculs moins prononcés autour d'une ligne moyenne. Les dernières observations et levés topographiques réalisés par la direction technique du port de Cotonou, confirme cette évolution du trait de côte depuis 1995. Cependant, les lâchers successifs rendront très actifs les chenaux et provoqueront dans le temps l'érosion des hauts-fonds de la plaine alluviale sur lesquels se trouvent des villages comme Djondji qui risquent de disparaître. Cette instabilité de l'embouchure, aussi bien du Mono que de l'Aného, est bien montrée par l'analyse des données sédimentologiques et surtout hydrologiques tout en précisant que le régime induit par l'exploitation du barrage maintient dans la passe une vitesse importante de l'ordre de 5 m/s. En conséquence, de décembre à avril, l'embouchure sera marquée par une relative stabilité dynamique. Par contre, pendant le reste de l'année avec une vitesse plus importante, elle connaîtra une forte instabilité accompagnée d'érosions.

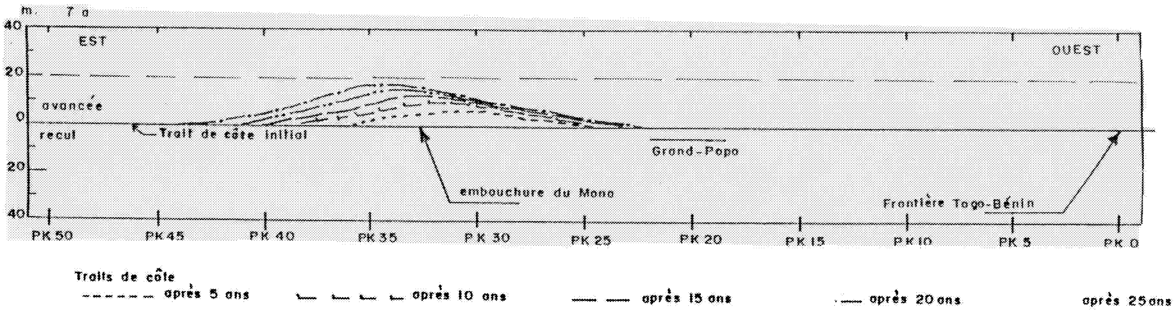


Figure 7a - Apports du Mono (100 000 m³/an). Situation montrant un apport sédimentaire à l'embouchure avec effet d'accumulation jusqu'à une douzaine de kilomètres à l'Est de l'embouchure.

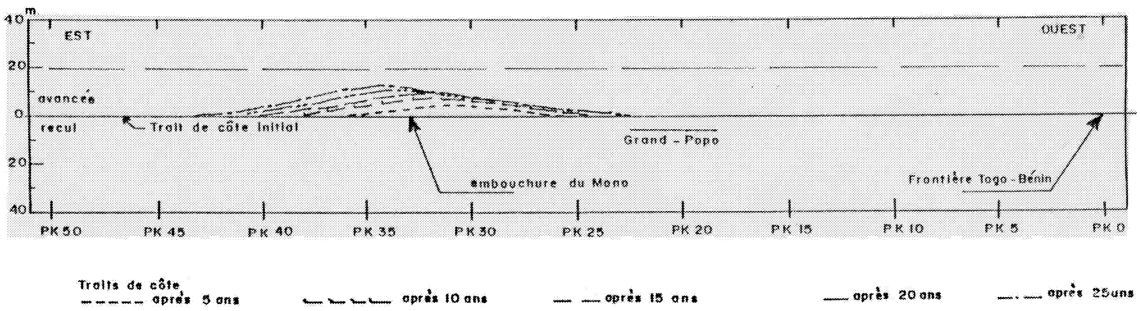


Figure 7b - Apports du Mono (75 000 m³/an). Situation montrant un apport sédimentaire théorique un peu moins important ; recul du trait de côte.

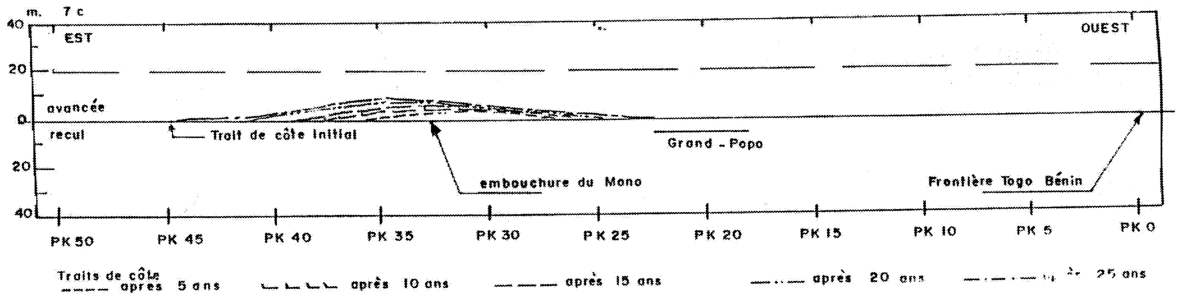


Figure 7c - Apports du Mono (50 000 m³/an). Situation montrant un apport sédimentaire théorique moins prononcé autour de l'embouchure du Mono; recul du trait de côte.

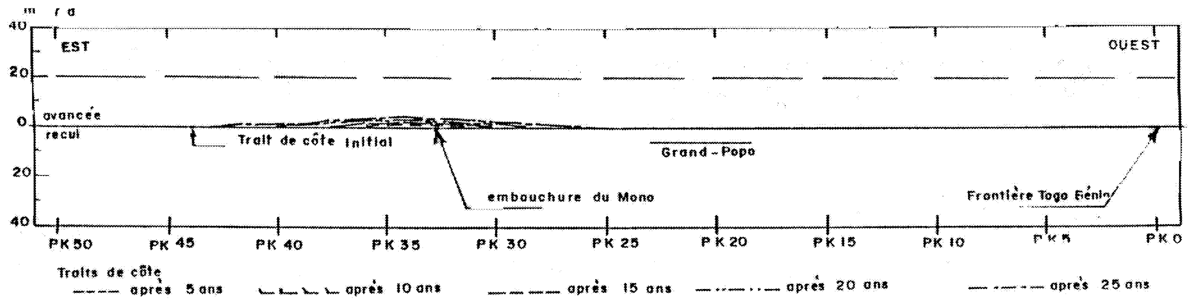


Figure 7d - Apports du Mono (25 000 m³/an). Situation montrant un apport sédimentaire théorique peu significatif autour de l'embouchure ; recul du trait de côte.

Figure 7. Différents scénarios d'évolution du trait de côte à l'embouchure du Mono (après Blivi 1998).

L'érosion sur la côte togolaise pourra affecter la côte du Bénin sur environ une dizaine de kilomètres après la frontière. Mais, elle ne se combinera pas avec celle provoquée par le barrage sur la côte, dans la zone de l'embouchure. Une zone d'ensablement sur 12 km de côte entre Agoué et Grand Popo sépare les deux zones d'action régressive (Figure 8).

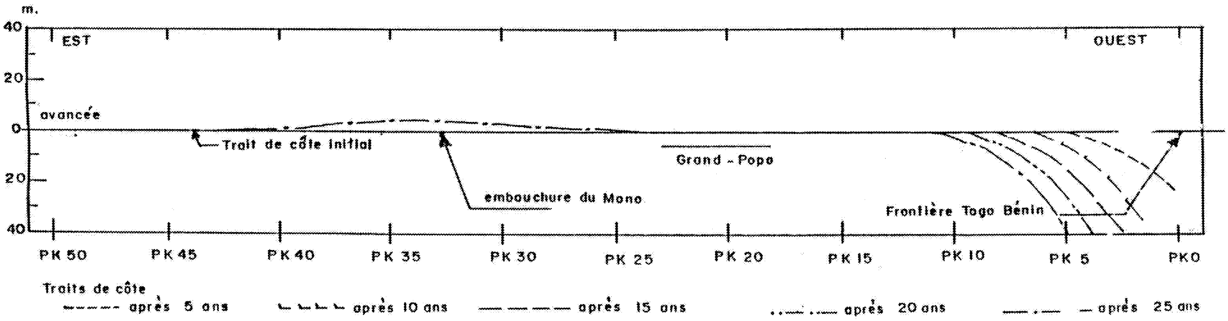


Figure 8. Scénarios d'évolution du trait de côte liés à la réduction du transit sédimentaire à la frontière Togo-Bénin. (après Blivi 1998).

- *Apports du Mono à l'embouchure estimés à 25 000 m³/an ; recul du trait de côte*
- *Transit sédimentaire variant de 1,3 à 0,9 M m³/an ; recul du trait de côte*
- *Accumulation de sable entre les deux secteurs d'érosion*

Conclusion

Les connaissances sur les progressions moyennes annuelles du rivage répondent généralement à des préoccupations relatives à l'aménagement, au développement et à la recherche de solutions en matière de protection. Les conséquences des ouvrages érigés sur les fleuves sont bien connues. Il importe de placer des informations scientifiques à la portée des décideurs pour permettre d'éventuelles actions en vue de limiter les dégradations des différents secteurs côtiers. Des mesures d'adaptation à l'amincissement, au recul, voire à la rupture périodique ou définitive du cordon barrière seront proposées avec l'installation d'ouvrages comme les épis ou les barrages de contrôle de salinité. et à l'ouverture du système lagunaire sur l'océan aux conséquences sociales et économiques graves.

Cette étude de sédimentologie prévisionnelle soulève plusieurs préoccupations dont principalement la mise en place de stations de suivi de l'évolution du trait de côte. Cette opération sera accompagnée d'une carte de sensibilité de la côte à l'érosion à une échelle spatiale figurant un levé tous les 500 m, élaborée pour apprécier les déplacements des points d'érosion et les configurations du rivage. Un suivi de l'influence des eaux marines dans les écosystèmes lagunaires et de mangrove sera également envisagé.

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4.11 The Niger Delta as a receptacle and the Niger River flux into the Atlantic Ocean – the role of upstream change and coastal hydrodynamics

I. Balogun, L. Oyebande, A. Adewale, and O. Adeaga

Extended abstract

The Niger Delta lies between latitudes 4°30`N and 7°N, and longitudes 5°E and 9°E. It covers an estimated land area of some 67,140 km^2 and currently has five states (Bayelsa River, Akwa-Ibom Delta and Cross River) as its constituent administrative divisions. Its climate is typically humid with total annual rainfall in excess of 2400 mm annually. Rainfall distribution also defines the double maxima characteristic of such areas. Temperature ranges between 27°C and 30°C.

The total population is approximately 11.4 million, but population densities are high as only 30% of the entire region is habitable. Population density may average 169.5 persons/km^2, but densities of 400/km^2 occur in some places. The main occupations traditionally are fishing, farming and other land-based activities such as hunting and fuel-wood harvesting and selling. This is mostly the situation in the rural riverine areas from where the crude oil and associated gases are exploited. In cities, secular and other service occupations predominate.

The hydrology of the area is controlled by major and minor rivers that have intricate links with a creek network that serves as transportation channels for sediments and other materials from the hinterland. In response to tidal dynamics, these either experience fluxes or become sinks for nutrients, sediments and other materials. Characteristically, low tides bring about flow towards the Atlantic Ocean while high tides effect flow in the other direction.

Due to the generally low-lying nature of a significant part of the Niger Delta and the prevailing high groundwater table, more than 70% of the land area is wetlands that are submerged for different periods of the year. Vegetation varies from freshwater to mangrove (saline) species, depending to a large extent on the biochemistry of the existing waters, sediments and soils. The uniqueness of each of these ecological units and their sensitivity to modification and change are predicated on these innate characteristics.

Geologically, the Niger Delta is a zone of active recent sedimentation. The Sombreiro-Warri Deltaic Plain sediments of early Holocene to late Pleistocene era are the oldest Quaternary sediments. They are principally coarse and fine sands with minor silt and clay. These are overlain by sediments of mangrove swamp origin that vary from fine to medium sands, the wooded back- and freshwater-swamps, and the meander belts which consist mainly of sand, silt and clay in different proportions. Two hydrogeological provinces, the coastal alluvial and the coastal sedimentary lowlands, are identifiable. A high water table, usually at less than 2 m depth, characterises the former, while the latter consists of unconsolidated and highly porous material. The high permeability and the shallow groundwater table enhance interactions between surface and groundwater in the region and that relationship also accentuates the risk of groundwater pollution particularly in the case of oil spills.

The Niger Delta is endowed with diverse natural resources. The most prominent of these are the vast reservoirs of crude oil and associated gas which have become the mainstay of the national economy. The location of this 'vehicle' of economic empowerment within that environment that has brought the entire area into limelight. The area has also attracted much attention and discussion because of the degradation that has occurred in the process of exploiting those resources. The agents of impairment of the coastal and marine environment include domestic sewage, industrial effluents, petroleum hydrocarbons, dredged materials and garbage. These have degraded the aquatic resources for recreation and transportation. The effects of mineral oil mining are aggravated by rapid urbanization and industrialization in coastal settlements. Frequent oil spills have adversely affected fish stocks, wildlife and the fragile mangrove ecosystem.

The situation has assumed such critical social and political dimensions that the environmental neglect of the area and its people over the years has threatened the corporate existence of Nigeria. In fact, the rebellious youths in the Niger Delta are yet to be placated, as there are still incidents of interference with oil prospecting and production activities within the predominantly riverine area.

As noted above, the Niger Delta is mostly a flat, low-lying swampy sub-basin criss-crossed by a myriad of rivers and creeks. Its topography, geology and soil properties and heavy and frequent rainfall subject the area to severe annual flooding and erosion. The Niger Delta is subsiding as a result of both natural compaction of sediments and also due to oil, gas and water extraction. The rate of subsidence during the last 10 years is as much as 7 cm at Bonny. Superimposed on the subsidence is the accelerated sea-level rise (ASLAR) driven by global warming which could add up to 30 cm of sea-level rise in the next three decades. The implication of such changes at the coastline and for the coastal zone could be grave for the natural resources and the inhabitants. A zone of 40 km could be lost to the ocean in the next two decades.

The Niger Delta has its apex south of Onitsha, some 375 km from the ocean. The Niger River bifurcates south of the Nun and Forcados rivers. From there the depth expands to 270 km of coastline using the considerable discharges of water and sediments in building up and progressively extending into the Atlantic Ocean. The seaward hydrodynamic zone of the delta is completely tidal while that of the freshwater zone is determined largely by the discharge from the river. The transitional/estuarine areas are dominated by tidal flows during the dry season and by freshwater during the wet or flood season of the river system.

The delta is the receptacle of the floodwaters of the Niger River system and stores much of the inflow for varying periods of time. During the wet season (July-October), about $119 \times 10^9 m^3$ of water is discharged into the delta and constitutes the principal source of water. The run-off is distributed through a dense network of distributory rivers, creeks and estuaries of which the principal ones are the Forcados, Nun, Ase, Imo, Warri and the Sombriero which form an interconnected network that ensures rapid communication of pollutants such as oil-spills. The network also maintains and delivers a dynamic equilibrium between saline, estuarine and freshwater bodies with a complex groundwater system of pathways and reservoirs.

The intersection of the Niger basin with the ocean is effected by the delta through a series of exchanges which impact the coastal zone significantly through 20 river outlets The Niger River finally discharges its water and sediments fluxes into the Atlantic Ocean where distributive forces come into play:

⇒ flooding of the coastal wetlands
⇒ coastal erosion and destruction of infrastructure.
⇒ saltwater intrusion into swampy freshwater and groundwater resources
⇒ through coastal lagoon and estuaries which have their own effects.

The delta also mirrors the impact of upstream water projects (dams and their reservoirs) as well as the prolonged 30-year drought of the Sudan and Sahel. There was a sudden decrease in river run-off soon after the construction of dams and reservoirs, which unfortunately coincided with the severe drought years (e.g., 1971-73, 1983-84.) The discharge rate in the 1983-84 was observed to have dropped by 20% in the Niger Delta. In general, regulation by dams lowered the flood levels and reduced the capacity of flows to transport large volume of sediments during the wet season, which normally accounts for the bulk of the annual sediment transport. As another result of high evaporation rates and the extensive nature of these shallow reservoirs, large volumes of their storages are lost to evaporation and to the Niger basin (though not to the global hydrological system). These losses in terms of the total annual inflow into the reservoirs amount to 20-30%. In addition, the dams retain the bulk of the sediments. As Nigeria's dams are traditionally over-designed, they tend to retain over 70% of dissolved sediments intercepted by them.

Extreme construction and dredging of canals for transportation and communication in the many isolated riverine communities have contributed to anthropogenic impact in the Niger-delta. These structures often change the water flow pattern, disrupt sediment transport and deposition and the level of salinity and could lead to destruction of fishing grounds and death of forests. The dredged spoils produced are found to constitute a serious ecological hazard. The proposed dredging of the lower Niger has attracted much outcry from the general public and NGO's and the individuals as well as groups of stakeholders knowledgeable in environmental issues. Environmental assessments have indicated that the impact of the huge volumes of dredge spoils on the aquatic and forest environments are expected to be severe.

Over-abstraction of groundwater in coastal/estuarine cities such as Port Harcourt and Warri may result in the lowering of the water table/piezometric level and hence reversal of the hydraulic gradient at the groundwater-seawater interface. If this happens, the saline water intrusion at the interface will extend the zone of contamination.

The most probable agent of change is oil prospecting/mining. Activities undertaken in the search and production of oil have already been implicated in some oil-spills. Gas flaring, regarded as a "safety measure" put in place by all the oil prospecting companies in the Niger Delta field in the absence of a more cost-effective measure, is another source of impact. Finally, there are implications of negative impacts on humans within the area, most of whom are already living below the poverty line and who directly bear the brunt of such mishaps.

4.12 Nutrient fluxes between land and ocean, and effects of human-induced activities: case study of Ondo State coastal wetlands, Nigeria

Yemi Akegbejo-Samsons and A.M. Gbadebo

Abstract
This paper examines the chemical composition of the rivers, creeks and floodplains that constitute the Ondo state coastal wetland system. The report is based on part of the work done for a Ph.D research in 1995. Water samples were analysed for general chemical factors, nutrients and trace elements.

Results show that the wetland system can be categorised as freshwater, brackish water and marine. While the freshwater wasslightly acidic and very rich in organic matter and biogenic nutrients, the brackish water was alkaline and full of chloride and magnesium. The chemical composition varies with season and tides for all the three categories: generally high in the dry season and dilute in the wet season. Effects of the chemicals and nutrients values on fish production were not significant.

Effects of human-induced activities such as dredging, sand harvesting, marine transportation and other fisheries-related activities are highlighted. The need for a regular monitoring of the coastal wetlands is advocated.

Keywords: Nutrient fluxes – land – ocean - coastal wetlands.

Introduction

Ondo state is one of the eight coastal states of Nigeria, bordering the Atlantic ocean. The state consists of 18 local government areas and has a population of over 2.8 million. The lowland wetland area is bounded in the east by the Benin River of Edo State, in the west by the Ogun waterside and in the north by a land mass whose inhabitants are predominantly farmers, hunters and fishermen.

The coastal wetland system is parallel to Nigeria's south-west coastline, and is characterised by extensive lagoons, creeks, estuaries and river delta systems. It lies between latitudes 6^0N and 7^0N, and longitudes 4^0E and 5^0E. While the remaining parts of Ondo state can be reached by a network of roads, these coastal plains and swamps can only be reached and explored by boats and canoes. Quite recently, a large reserve of bitumen was discovered close to these areas. This wetland , which is pierced by the Oluwa River, is the major fish resources ground of Ondo state (Akegbejo-Samsons 1995, 1997, 1998, 1999).

This study is concerned with the nutrient fluxes between the land and the ocean that constitute the Ondo State coastal wetland. The main object is to determine the levels of some important nutrients and trace elements in the study area and their effects on fish distribution and yield in the area.

Materials and methods

Study area
The study area was divided into three categories for effective data collection and verification:
(i) fresh water (rivers, canals, flood-plains);
(ii) brackish water (creeks, lagoons, estuaries); and
(iii) salt water (the coastal fringe).

Within each of the categories, sampling stations were selected as follows:
- fresh water - Oluwa 1, Oluwa 2, Igbokoda;
- brackish water - Mahin, Atijere, Igbekebo; and
- marine - Aiyetoro, Orioke Iwamimo, Zion Pepe and Alagbon.

Water analysis
Water samples were taken from the selected stations in Winkler's bottles and plastic containers and brought in iced containers to the laboratory of the Federal University of Technology, Akure for analysis during 1994

and 1995. The following parameters were analysed based on the methods specified in AOAC (1984): calcium, magnesium, sodium, potassium, alkalinity, sulphate, chloride, silicate, nitrate and phosphate. Trace elements such as copper, nickel, chromium, cobalt and iron were also analysed to show their level of concentration.

Resources evaluation and human activities
A desk review was carried out to collect information on the location of fishing communities and human population in the study area. Questionnaires and on-the-spot evaluations of the following were done:
(a) fauna availability, management and conservation;
(b) (b) inventory of all coastal resources based on harvest data of fishermen groups, and
(c) (c) decision-making in resource allocation and exploitation.

Data analysis
Data collected from the various study sites were then computed as follows:
(i) Fish species harvest trends were observed over time from the various locations; the fish species were identified and their composition and abundance determined.
(ii) The coastal resources were inventoried and categorised to thier various 'utility units'. Their various levels and modes of utilisation were assessed.

Results and discussion

Hydrological characteristics
The major hydrological and tidal characteristics of the study area are shown in Table 1. While the Oluwa River is the major distributary, other tributaries include the Kurawe Stream, the Talita River, the Mahin Canal and Alape Creek. The estimated total mangrove swamp area is about 60,000 hectares with a surface area of rivers, creeks and streams of about 38,000 hectares. Table 2 shows the information on the sampling sites. This is presented to show the variability in location as determined by the ecological niche of the individual stations and their relevance to spatial concentration of the tested parameters.

Trace elements concentration
The concentration of the trace elements is presented in Table 3. Iron concentration was highest in all the sampled sites, followed by copper and then cobalt. Concentrations were highest in the freshwater areas for iron, copper and cobalt, while nickel concentrations were high for marine sites. Generally, concentrations of trace elements decreased from the freshwater towards the marine.

Table 1. Major hydrological characteristics of Ondo state coastal wetland.

Major distributary	River Oluwa.
Major tributaries	Apostle Canal, Alape Creek, Ipare Stream, Talita River, Kurawe Stream, Mahin Canal.
Mangrove swamp area (hac):	60,000
Water mass area (hac) :	38,000
Mean depth of water level:	River Oluwa - 4.6 m Apostle canal - 4.8 m Mahin canal - 4.9 m

Table 2. Information on sampling stations.

No.	Category	Sampling site	Latitude	Longitude
1	Freshwater	Oluwa 1	$6^0$36	$4^0$04
2	Freshwater	Oluwa 2	$6^0$36	$4^0$04
3	Tidal freshwater	Igbokoda	$6^0$34	$4^0$06
4	Brackish water	Mahin	$6^0$35	$4^0$06
5	Brackish water	Atijere	$6^0$36	$4^0$07
6	Brackish water	Igbekebo	$6^0$39	$4^0$05
7	Marine	Ayetoro	$6^0$26	$4^0$08
8	Marine	Orioke Iwamimo	$6^0$24	$4^0$08
9	Marine	Zion pepe	$6^0$22	$4^0$07
10	Marine	Alagbon	$6^0$28	$4^0$06

Table 3. Concentration of trace elements (mg/l) in Ondo State coastal wetland. The sampling program was carried out during June-December 1995.

Sampling site	Trace Elements				
	Iron	**Nickel**	**Chromiun**	**Copper**	**Cobalt**
(1) Oluwa 1	0.71	0.01	0.01	0.30	0.24
(2) Oluwa 2	0.73	0.01	0.01	0.31	0.26
(3) Igbokoda	0.68	0.01	0.01	0.30	0.26
(4) Mahin	0.51	0.01	0.01	0.24	0.25
(5) Atijere	0.41	0.01	0.01	0.21	0.19
(6) Igbekebo	0.02	0.01	0.01	0.20	0.16
(7) Ayetoro	0.01	0.11	0.01	0.18	0.08
(8) O' Iwa mimo	0.02	0.10	0.00	0.17	0.08
(9) Zion Pepe	0.03	0.11	0.01	0.06	0.07
(10) Alagbon	0.03	0.11	0.01	0.06	0.06

Table 4 shows the chemical and nutrient composition. Values of pH, calcium and organic matter decrease as one moves from freshwater to the marine. However, values of major nutrients such as nitrate, chloride, sulphate, silicate, magnesium and sodium increase from the fresh water to the marine systems. Levels of salinity and alkalinity increase as we move from the fresh water to the marine environment. However, the level of phosphate remains significantly steady in all the ecosystems.

There was no significant result (P=0.05) between nutrient composition and fish species abundance. Higher values of calcium and potassium were recorded for the freshwater areas, probably due to the presence of Oluwa glass industry which empties its discharges into the upper region of the river. However during the dry season fish populations were found to be at the lowest levels. Farming activities were highest in the freshwater areas, while fishing was highest in the brackish water ecosystems.

Coastal communities and their activities

The fishing communities did not differ from one ecosystem to the other. However their activities varied from freshwater to brackish and marine environments. This constituted a significant impact on the intra- and inter-coastal activities within the study area. More than 82% of the members of the communities belong to co-operative societies where resource exploitation and management are formulated and passed as by-laws. This is more effective within the marine area than the freshwater, because human activities in the freshwater zone are restricted and specialised. These include using the water for irrigation and fish ponds. Socio-economic activities here include river fishing, farming and aquaculture.

Table 4. Chemical and nutrient composition (June to December 1995) in Ondo state coastal wetland.

		Sampling station									
Parameter	**Unit**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hydrogen ion	pH	6.8	6.9	6.8	6.2	6.2	6.3	6.0	6.1	6.1	6.1
Salinity (estimate)	%o	0.05	0.06	0.05	0.30	0.36	0.37	1.20	1.23	1.36	1.40
Oxygen	mg/l	6.5	6.8	6.9	7.0	7.0	7.1	7.3	7.0	7.2	7.1
Calcium	mg/l	132	131	136	93	94	96	63	64	63	63
Magnesium	mg/l	68	69	70	81	83	86	86	103	103	106
Sodium	mg/l	64	63	63	76	803	821	821	902	905	905
Potassium	mg/l	171	173	169	64	68	63	71	72	72	73
Alkalinity	mg/l CaCo3	23	23	22	25	25	26	24	36	38	36
Sulphate	mg/l	28	28	27	26	27	28	28	28	29	30
Chloride	mg/l	65	64	63	107	108	108	109	207	206	207
Silicate	mg/l	1.0	1.0	1.1	2.3	2.1	2.4	2.5	2.3	2.3	2.4
Nitrate	ìg/l	18	21	22	20	26	24	24	25	25	26
Phosphate	mg/l	34	36	38	32	33	34	33	33	30	28
O. matter	mg/l	3.6	2.7	3.2	3.1	3.2	2.8	2.8	2.6	2.7	2.8

Coastal communities within the brackish and marine zones rely mainly on capture fishery resources and other related aquatic resources. During the fishing months of the year, usually during the months of May to October, there is a population shift from the adjoining towns to the marine fishery. This is accompanied by over-capitalisation and an increase in fishing efforts to the detriment of the fishery. For example, an increase of over 68% of adult fishers occur every fishing season, a situation which is not good for the fishery.

Coastal resources and effects of human activities

An inventory of the coastal resources and the resultant effects of human induced activities is presented and discussed.

(a) Fisheries

The bulk of the living coastal resources exploited for food in Nigeria falls under the category of 'fish'. Nine distinct fish species of major and commercial importance were identified and their relative abundance rated using the landing size (weight and number). The fish of commercial importance were *Clarias anguillaris, C. gariepinus, Oreochromis niloticus, Gymnarchus niloticus, Chrysichithys nigrodigitatus, Polydactylus quadrifilis, Synodontis membernaceous, Bagrus bayad, Heterotis niloticus* and *Heterobranchus bidorsalis.*

(b) Dredging and sand-harvesting

Dredging and sand-harvesting together constitute a major economic activity in both the freshwater and marine zones of the study area. In the freshwater zone, sand is stockpiled using human labour, then the sand is transported using special trucks to the construction sites.

In the marine zone, special boats are used to ferry the sand to sites which are always many kilometres from the point of harvest. This activity has been found to be highly hazardous to the environment and to the fishery. While it disturbs other fishing activities, it also destroys the habitats of the fish species that nest close to the shoreline. For example, over 230,000 m^2 of sand is excavated annually within the Lagos Lagoon and reports show that certain endemic fish species are no longer found in the lagoon as a result of this disturbance. In this study area, man-made pools of water and artificial 'cayons' are some of the consequences of this environmental disturbance.

(c) Marine transportation
This sector of human activities is mainly a 'water-use' rather than a resource. Traffic of motorised large canoes and model boats was found to be very high along the main Oluwa River and in the canals, where over 75% of the fisher-folk rely on such mode of movement.

Generally the use of motorised canoes and boats was found to enhance resource exploitation. For example, a census of the boats used to convey passengers between Igbokoda and Ayetoro found there were about 22 boats, each doing three trips per day. Fish catches along these routes have been drastically reduced, presumably as a result of this river traffic. Incidences of oil pollution via discharges from petrol and diesel engines have been reported.

(d) Proposed bitumen project
A bitumen exploratory plant is to start soon, a few kilometres from this study area. This report seems very timely since there is a need to highlight the consequences of exploratory activities on the adjacent Oluwa River, which invariably will carry effluent(s) to the marine environment down stream.

Conclusion

Water quality in riverine estuaries is related to season. Quite often seasonal rains increase river discharge and watershed runoff, which serves to dilute nutrient concentrations in the riverine estuaries. This can be seen in Table 3.

Nutrient sources for the brackish and marine zones include load in the form of river discharge and rainfall runoff, and other 'contaminants' that might have been introduced by the various human activities, especially from fish pond effluents.

When the data from this study was compared to some of the data collected in the area before the commencement of the operations of the Oluwa Glass Industry, an increase in concentration of over 60% of the chemicals and nutrients was observed. This is probably due to the operations of the industry, coupled with the increasing human pressure on the coastal area, especially since the beginning of the exploratory surveys of the bitumen site, which is just a few kilometer to the coast of Ondo state.

It is recommended that constant monitoring of these parameters be carried out every year to ascertain the annual implication of the human activities in this area.

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4.13 Movement of minerals and nutrients from river basins in south-western Nigeria into the Atlantic Ocean

G.A. Bolaji, O.S. Awokola, A.M. Gbadebo and O. Martins

Abstract
South-western Nigeria is highly populated and experiences moderate to high industrial and agricultural activities. The major river basins located in this zone are the Ogun, Oshun, Yewa, Benin and Owena. Serving as a source of water supply to the communities along their courses, they also transport major effluents that result from human activities and dissolution of rocks underlying the watercourse. This paper summarizes a study carried out to determine the concentrations of nutrients and minerals carried by some of the rivers and the variations in quantities discharged into the ocean via lagoons.

Introduction

Research efforts on the hydrochemistry of rivers in Nigeria has centered mostly on major rivers. There are numerous drainage basins suitable for modelling studies but to date only very limited information is available on riverwater quality and quantity. Effort is being made to publish new data on the rivers of south-western Nigeria.

Surface waters in the region transport domestic and industrial wastes and most of these rivers also serve as important sources of water; the Ogun, for example, supplies the sprawling city of Lagos (11 million inhabitants) with water from the Oyan Dam, 60 km to the north.

The area is characterized by low relief with a N-S gradient and a NW-SE striking escarpment at an elevation of about 500 m in the north-west, where most of the rivers rise. Three vegetation zones can be identified in the hinterland: the savanna in the west, distinctively different from the high forest vegetation of the central and eastern sectors. Significant changes in land-use patterns have taken place over the years; extensive natural forests and forest reserves have disappeared due to rapid urbanization, commercial logging and agricultural activities. Swamps and mangrove forests cover the southern coastal and riverine areas adjacent to the lagoons.

The development of the Nigerian coastal zone is closely related to the separation of the African and South American continents between the upper Jurassic and the Upper Cretaceous. The coastal zone today consists of a series of estuaries and lagoons that provides a transition belt between the rivers and the Atlantic Ocean. Notable are Lagos and Lekki lagoons, Badagry, Omu and Ope creeks. These lagoons and creeks receive the discharges and effluents brought by the rivers from the hinterland. The Lagos Lagoon is a receptacle of domestic and industrial wastes from the city of Lagos adjacent to it. Lagos has the largest concentration of inhabitants (1700 people/km^2) in Nigeria and it has been the commercial center of the country since the middle of the 19th century. In addition to the seaport, the city houses about 40% of Nigeria's industry, thus supplying a complex mixture of domestic and industrial wastes into the lagoon.

This study was prompted by a decline in catch levels of a hitherto prolific commercial fishery in the lagoons, possibly a result of degradation of the aquatic environment. The transport of materials from six river basins to the Atlantic Ocean via the lagoons is being examined on the basis of the major chemicals carried as dissolved or particulate materials and the major environmental factors controlling the concentrations and loads.

This paper provides a summary of many field surveys carried out (Martins and Awokola 1995; Martins *et al.* 1999; Bolaji and Martins, accepted). It outlines the transport of dissolved materials from the drainage basins into the Atlantic Ocean through the lagoons and creeks. The significance of the work is to establish the catchment-ocean interaction and determine the relative contribution of dissolved and particulate materials by rivers into the coastal environment and their potential effects on the commercial fishing industry.

The Study Area

The river basins studied are in south-western Nigeria, 6°26'N - 9°10'N, 3°58'E - 5° 00'E (Figure 1).

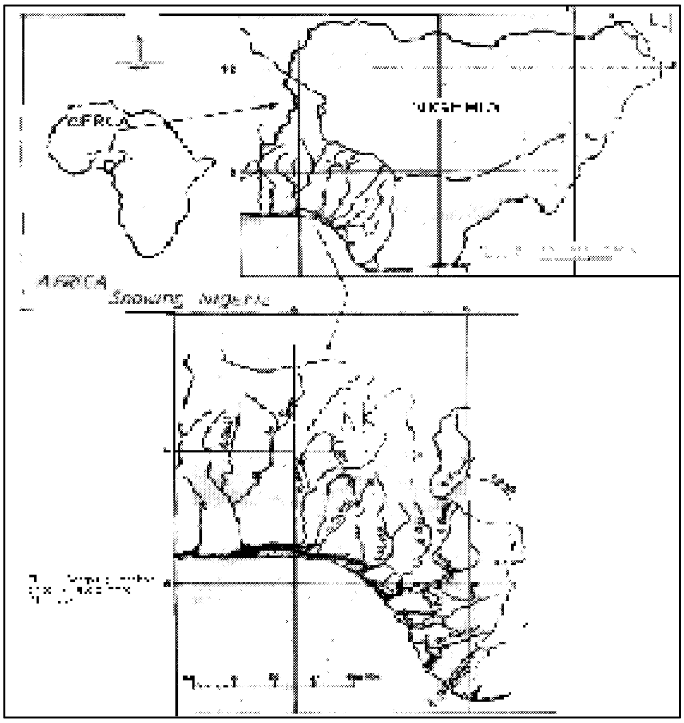

Figure 1. River basins under study in south-western Nigeria.

The rivers are highly seasonal in the northern sector of the basins, where they flow between May and November, displaying a mono-modal type of hydrograph, while the characteristic bi-modal hydrograph pertains towards the southern end of the basins. The mean annual rainfall ranges from 990 mm in the north-west zone to 2000 mm towards the south. Thus water levels in the lagoons are relatively low from December to March, during which there is an inflow of saline water from the Atlantic Ocean into the lagoons. Water and sediments are flushed from the lagoons during the rainy season.

The rock sequence in the area starts from the Precambrian Basement. This consists of quartzites and biotite schist, hornblende-biotite, granite and gneiss. The foliation and joints on these rocks control the course of the rivers, leading to a trellis drainage pattern, particularly towards the north of the study area. Sedimentary rocks towards the south of the study area are Cretaceous and Recent. The oldest of them, the Abeokuta Formation, consists of gray sand intercalated with brown to dark gray clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base. The Ilaro formation and the coastal plain sands (Benin Formation) are similar lithologically, distinguishable only by poorly developed unconformities.

Materials and Methods

Water analysis

Water samples for chemical analysis were taken in 25 ml plastic bottles. They were stored in cool bags and transported to the laboratory for analysis. Sampling points are between 20 km and 60 km from the Atlantic Ocean and well-distributed to reflect inputs from areas of different land uses. Chemical parameters were analyzed by Colorimetric, Electro-photometric and atomic absorption spectro-photometric (AAS) methods (Martins and Awokola 1995; Martins *et al.* 1999).

Sediment Samples Analysis

Sediment samples from the top 4 cm layer of the cores obtained at specific locations in the lagoon were stored in clean, labeled polythene bags at -18°C. Sampling stations were selected on the basis of their nearness to known sources of inputs of domestic and industrial wastes and of river water washed into the lagoons. The analyses were performed using Perkin Elmer 1100 AAS and Perkin Elmer 5000 AAS machines (see Martins *et al.* 1999).

Results and Discussion

Table 1 shows the results of minerals and nutrients concentrations in some of the rivers studied. The river discharges reflect the relationship between water quantity and the amount of materials being carried in solution. The sum of the total dissolved solids (TDS) was derived from conductivity values. The minerals content of the rivers is generally low, varying between 18 and 121 µs/cm at 25°C. Rivers in the Yewa basin have the lowest conductivity values, mostly 18-20 µs/cm at 25 °C except in the Ela/Ilaro and Irori/Aiyetoro where conductivities are around 59 µs/cm at 25°C. The main rivers, Ogun, Oshun, Ibu and Yewa have the highest values (103, 101, 107 and 111 µs/cm at 25°C respectively).

Table 1. Chemical characteristics of rivers under study.

River Locality	Discharges (m^3/s)	Cond. (µS/cm at 25°C)	Dissolved Oxygen(mg/l)	Sodium (mg/l)	Potassium (mg/l)	Calcium (mg/l)	Magnesium (mg/l)	Bicarbonate (mg/l)	Chloride (mg/l)	Sulfate (mg/l)	Nitrate (mg/l)	Total Diss. Solids (mg/l)
Igbin/Ifo	0.56	80	5.5	6.7	0.8	6.0	2.6	30.8	2.8	2.0	2.5	61.1
Ilo/Otta	0.105	52.4	5.0	7.1	1.2	6.0	2.7	22.2	6.0	1.5	2.4	51.6
Iju/Otta	Nd	83.2	6.4	10.3	1.2	9.8	4.1	23.8	6.7	1.4	3.0	79.8
Yewa/Ajilete	1.0	111	6.0	9.0	1.2	8.8	3.8	42.7	6.8	2.0	3.1	63.6
Ela/Ilaro	0.12	58.6	5.8	6.2	0.2	7.2	3.0	33.8	6.7	2.0	3.1	63.6
Orori/Aiyetoro	0.30	58.7	7.5	8.5	1.2	7.4	3.0	43.8	3.2	0.96	3.0	70.2
Owuru/Shagoye	0.09	63.4	6.8	6.7	0.4	7.0	2.9	45.4	3.1	2.4	2.5	77.3
Ibu/Ajura	Nd	107	8.0	12.9	5.6	15.4	6.4	57.3	4.6	1.9	2.9	136.1
Erin-Ogun/Ogere	0.07	51.8	4.8	4.1	0.4	4.2	1.8	22.2	3.3	2.0	1.9	41.0
Ibu/Sagamu	1.7	121.6	8.5	13.8	1.9	11.8	5.0	48.2	2.1		2.5	113.9
Eren/Odogbolu	1.3	37.6	5.0	4.0	0.4	3.4	1.5	22.0	3.2	2.9	3.1	40.1
Eren/Ikenne	0.25	56.3	6.0	7.6	1.6	5.2	2.2	30.0	3.1	1.9	2.5	67.1
Yemoji/Ijebu-ode	1.5	27.5	6.0	2.8	0.4	2.8	0.98	12.2	3.3	2.4	2.6	36.5
Oshun/Apoje	Nd	101	8.5	13.8	3.5	8.6	3.4	54.3	4.3	0.5	2.5	108.3
Oshun/Ogbere	Nd	101.3	9.2	40.0	3.5	7.8	3.7	41.5	4.2	0.9	3.1	93.2
Lepiya/Ogbere	Nd	48.2	8.5	6.7	1.6	4.8	1.8	12.2	3.2	0.5	1.9	43.6
Ifara/Abigi	Nd	20	7.8	1.8	0.2	1.8	0.7	5.4	3.5	1.4	2.9	24.1
Agbure/Agbure	0.15	18.2	5.2	1.4	0.2	1.4	0.5	5.5	3.2	1.5	3.2	22.3
Ilusin/Erifun	0.40	18.2	5.6	1.6	0.3	1.2	0.5	5.6	2.8	1.9	3.0	21.5
Aofa/Aofo	0.15	18.8	6.2	1.8	0.2	1.8	0.7	5.5	2.9	2.0	2.5	26.6
Sowore/Ibiade	0.21	20.4	5.8	2.1	0.4	1.0	0.5	5.4	4.2	0.9	2.6	20.5
Ogun/Abeokuta	Nd	103.6	7.6	13.6	3.1	8.6	3.8	58.5	2.7	2.9	2.0	116.8

Nd. – Not determined

Source: Adapted from : Martins and Awokola (1995)

Predominant drainage basin lithology is the principal factor determining the type of dissolved substances found in surface waters (Meybeck 1980; Martins 1988). Other factors that play a modifying role are climate, vegetation, relief, chemical reactions and atmospheric input. The influence of the latter depends on the distance of the sampling points to the ocean, amount of atmospheric pollution and the prevailing wind direction (Bolaji and Martins, accepted).

With the exception of the Ogun and Oshun basins, where crystalline rocks cover most of the upper reaches, sedimentary rocks predominate in the drainage basins of all the rivers under study. The rock types are mostly recycled sands and clayey materials that must have originated from eroded crystalline rocks. They are derivatives of the chemical weathering of minerals mostly from feldspar, mica and amphibolite groups under the influence of atmospheric carbon dioxide according to the following reaction:

$2NaAlSi_3O_8 + 2CO_2 + 3H_2O = Al_2SiO_4 + 2Na^+ + 2HCO_3 + 4SiO_2$

It is apparent from this reaction that the bicarbonate, which forms a major part of the TDS, is derived from the atmosphere and soil carbon dioxide.

In a similar study carried out on the Ogun River, but sampled at locations far downstream, and the results presented on Table 2, the concentration of chloride remained almost constant but that of nitrate increased considerably. The average value of chloride dropped from 2 mg/l upstream to 1.93 mg/l downstream while that of nitrate increased from 2 mg/l upstream to 4.7 mg/l downstream. The nutrients, especially nitrates, may have originated from agricultural effluent that found its way to the river course. Iron is the most abundant mineral followed by manganese, nickel and cyanide. The iron and manganese may have come from the erosion of laterite crusts that dominate the drainage basin while traces of nickel and cyanide are likely to be derived from inputs of untreated domestic and industrial wastewater.

Table 2. Minerals and nutrients concentration in the Ogun River.

Sample	Manganese Mn (Mg/l)	Iron Fe (mg/l)	Nickel Ni (mg/l)	Cyanide Cn (mg/l)	Chloride Cl (mg/l)	Nitrate No3 (mg/l)
1	0.01	0.09	Nd	0.001	2.0	7.0
2	0.04	0.19	0.01	0.001	1.0	8.0
3	0.06	0.08	Nd	0.001	2.0	5.0
4	0.05	0.10	0.00	0.002	2.0	10.0
5	0.06	0.09	0.00	0.002	2.0	7.0
6	Nd	0.05	Nd	0.001	2.0	6.0
7	0.13	0.17	0.08	0.005	2.0	7.0
8	0.03	0.08	0.00	0.002	3.0	1.0
9	0.03	0.46	0.04	0.001	2.0	5.0
10	0.05	0.11	0.08	0.003	2.0	2.0
11	0.08	0.14	0.09	0.003	2.0	6.0
12	0.12	0.05	0.11	0.004	2.0	2.0
13	0.07	0.06	0.06	0.003	2.0	3.0
14	0.06	0.07	0.05	0.002	2.0	0.0
15	0.03	0.04	0.03	0.001	1.0	1.0

Nd – Not detected

The results of a study on two tributaries to the Ogun River, the Ewekoro and Onijanganjagan rivers, are presented in Tables 3 and 4. Average concentration values obtained from the Ewekoro River indicate that, as well as $CaCO_3$, silicate is also predominant. Calcium carbonate and silica are from silicon dioxide; tricalcium silicate ($3CaSiO_2$) and dicalcium silicate ($2CaSiO_2$) are used in cement manufacturing (West African Portland Cement Plc.) in the area. Effluent runoffs from the mining and industrial premises are channelled into the Ewekoro River. Results of average concentration values obtained from the Onijanganjangan River (Table 4) also indicate that calcium carbonate and silica are dominant, but in far lower quantities than in the Ewekoro River. The Onijanganjangan River is also being polluted by effluents from some other industries located close to the river. The Ewekoro and Onijanganjangan rivers join the Ogun River at locations about 5 km apart.

Table 3. Average concentration values at three points along the Ewekoro River.

Station	Fe (mg/l)	Al (mg/l)	Si (mg/l)	Ni (mg/l)	Cn (mg/l)	Zn (mg/l)	Ca (mg/l)	$CaCO_3$ (mg/l)
A	0.04	0.03	0.51	0.227	0.007	0.30	50	125
B	0.077	0.003	0.45	0.013	0.010	0.30	60	150
C	0.06	0.000	0.46	0.00	0.000	0.30	61	152

Table 4. Average concentration values at three points along the Onijanganjangan River.

Station	Fe (mg/l)	Al (mg/l)	Si (mg/l)	Ni (mg/l)	Cn (mg/l)	Zn (mg/l)	Ca (mg/l)	$CaCO_3$ (mg/l)
A	0.053	0.007	0.500	0.227	0.004	0.267	30	75
B	0.083	0.000	0.483	0.033	0.007	0.200	17	43
C	0.230	0.000	0.427	0.053	0.007	1.000	17	42

A summary of the results of trace metal concentrations in the surface sediments is presented in Table 5.

Table 5. Concentrations of acid-leachate (non-residual) trace elements (mg/kg dry weight) in surface sediments of specific effluents in Lagos Lagoon.

Samples	Cadmium	Lead	Nickel	Vanadium	Chromium	Copper	Zinc	Iron
1	0.04	4.4	6.5	4.8	4.2	1.3	43.1	26217
2	0.02	1.9	1.1	1.5	0.6	1.6	16.3	1902
3	0.013	6.3	8.9	16.9	5.1	5.2	53.4	18727
4	0.09	4.9	3.3	12.3	1.8	3.8	36.7	7481
5	0.02	1.1	0.6	1.8	0.3	0.9	8.3	734
6	0.12	0.6	0.3	1.3	0.5	0.6	7.3	1166
7	0.26	40.6	5.6	23.9	7.2	9.0	227.7	8236
8	0.39	29.4	8.5	27.2	8.5	9.7	174.0	5637
9	0.03	0.8	3.6	2.7	2,3	1.2	19.1	8439
10	0.11	3.3	12.6	18.9	7.9	6.9	67.3	31375

Iron has the highest concentration of followed by manganese lead, nickel and zinc. While most of the iron and manganese may have come from the erosion of laterite crust predominant in the adjacent drainage basins (Ogun and Oshun river basins), the same cannot be said for lead, nickel, zinc and copper. High concentrations of these metals in some tributaries of the Ogun River can be attributed to untreated effluents from the galvanizing paint, textile and beverage industries scattered within a distance of less than 30 km from the lagoon. Ajao *et al.* (1996) found that high concentrations of cadmium, nickel, vanadium, chromium, copper and mercury come from inputs of untreated domestic sewage, municipal garbage, wood shavings and industrial waste waters from factories located on the shores of the lagoon. Though not properly documented, it is assumed that inputs of minerals and nutrients received by the coastal waters have been affecting the fragile aquatic environment and might have been responsible for the rapid decline of economic fishing from the lagoons. An informal survey among the fishing communities also revealed that fishermen are now venturing into open ocean waters beyond the lagoon environment to obtain viable catches.

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4.14 Impacts of proposed dams on the Thukela estuary and inshore marine environment, KwaZulu-Natal, South Africa

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Introduction

South Africa is a dry country with a national rainfall average less than 500 mm. This is about half the global average. Rainfall is patchy and variable, declining rapidly from peaks of *ca.* 1,250 mm *per annum* in parts of the east to less than 200 mm in the extreme west. Areas of high water demand do not coincide with areas of high availability with the result that virtually all major rivers are dammed and South Africa is one of the world's leaders in techniques of inter-basin transfer. Present forecasts indicate that despite innovative techniques in relation to the use of national precipitation, demand will outstrip supply in the next 10 to 20 years. It is probably fair comment that the water-associated problems faced by the country revolve primarily around availability of the resource rather than simply water quality, although water pollution problems do exist and salinisation and eutrophication are locally significant.

In the coastal zone, many estuarine systems have been affected through physical development of the banks and floodplains including inconsiderate placing of road, rail and bridge systems and the development of harbours in estuaries at East London, Durban and Richards Bay. Water quality can be a problem in these environments, but the biota of estuaries and coastal water bodies is still surprisingly rich even in harbour areas. Inshore water quality, despite the presence of marine outfalls, is typically high as a result of the generally narrow continental shelf, the high energy, wave-washed coastline and the associated strong currents all of which combine to generate high dispersive powers. Marine pollution events are primarily the result of periodic but relatively uncommon oil spills.

Arguably one of the greatest threats faced by South African inland waters and estuaries at present arises out of the demand for fresh water. This has resulted in the construction of large numbers of dams which have greatly modified natural flow patterns. Concomitantly there have been major changes in environmental legislation which now recognizes the significance of minimum flow levels in rivers for the functioning of these ecosystems. Simultaneously there has been an increasing appreciation of the significance of freshwater inputs into estuaries and most recently the significance of freshwater inputs into the inshore marine environment. These concepts are now becoming embodied in legislation. The South African Department of Water Affairs and Forestry (DWAF), which formerly concerned itself with landlocked freshwater bodies, now finds itself at an interface between the freshwater and marine environments and having to concern itself with the potential environmental impacts of dams in the Thukela catchment on the Thukela Banks, the only significant coastal shelf area in the sub-tropical part of the country. Although there are some inpoundments, the bulk of the Thukela catchment remains undammed and the present proposals for two dams represent potential significant effects on the system. This study was therefore undertaken with the aim of assessing the potential ecological and economic impact of these dams on the coastal and shelf environments. The study is ongoing and the planned date of completion of this phase is the end of July 2000.

The Thukela system

The Thukela (Tugela) River catchment (Figure 1) lies on the east coast of South Africa in the province of KwaZulu-Natal. The area has the distinction of having one of the steepest gradients in the world, rising from sealevel to the Drakensberg plateau at an altitude of *ca.* 2,000 m, with peaks of *ca.* 3,000 m, within a distance of 180 km from the coast. This mountain massif is the country's major watershed.

The catchment of the Thukela has an area of 29,100 km^2 and a Mean Annual Runoff (MAR) of *ca.* 4 $600x10^6$ m^3 . It is the largest eastward flowing river in the country being exceeded only by the Orange-Vaal system which rises on the same plateau but flows westwards to the Atlantic Ocean. The Thukela source lies at an altitude of 3,100 m at a point 250 km from the coast. Along its 405 km course it flows through an incised bedrock channel within a narrow floodplain never more than 1 km wide.

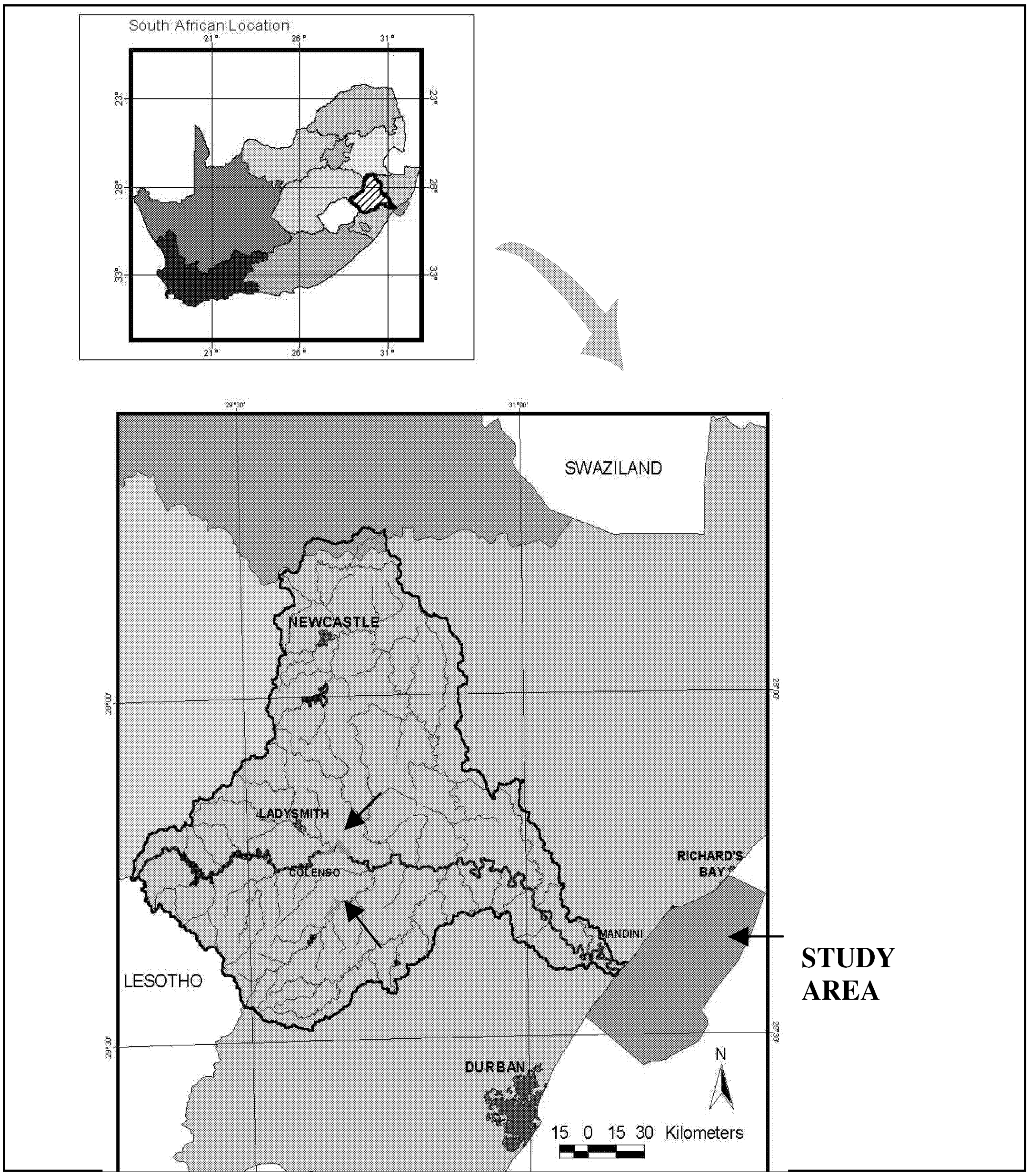

Figure 1. The Thukela catchment and study area. The proposed dams are arrowed.

The average annual sediment load is 6.79x10^6 m^3 of which 1.02x10^6 m^3, or roughly 15% is bedload. Accelerated erosion occurred from the 1930's onwards, due, depending on the authority quoted, to bad farming practices or climatic factors. Present trends are towards less erosion.

Flooding is a characteristic of virtually all South African rivers and major floods were recorded in 1893, 1925, 1984 and 1987. The peak flood volume in the 1925 event reached 15,100 cumecs and a total sediment discharge of 42.8x10^6 m^3 or nearly six times the annual average. 60% of the sediment was derived from channel scour and 40% from the catchment.

The Thukela River lies in a summer rainfall area. Floods in September at the end of the austral mid-year dry season carry more sediment than floods in the tropical cyclone season (January-February). The catchment straddles the zones influenced by sub-tropical, frontal systems and tropical cyclones which peak in September and December-March respectively. Both weather systems can produce significant floods.

The September 1987 event was caused by a frontal system and caused a peak discharge of 10,500 cumecs. The tropical cyclone of March 1925 generated a peak of 15,100 cumecs.

The geological interpretation of the appearance of the river course is that extreme flood events are responsible for channel formation. The regional maximum flood has been calculated at 20,000 cumecs and the estimated sediment load during such an event has been estimated at several orders of magnitude higher than the 1987 figure. This would make such extreme events highly significant in the sediment dynamics of the shelf. Flood conditions result in major sediment efflux and a plume extending 3-5 km offshore and up to 15 km northwards with a limited extent to the south because of the prevailing northerly long shore drift. Two of the six sub-catchments of the system will be affected by the proposed dams and these are responsible for 40% of the total discharge and 25-30% of the total sediment load.

The Thukela estuary is dominated by river flow, thus qualifying it as a "river mouth" rather than a true estuary. The northern limit of the estuary mouth is fixed by a rocky promontory towards which the mouth tends to meander. The normal cycle is for a flood to scour the barrier, after which the barrier begans to re-establish itself, usually with the mouth located to the south side of the estuary. It then begins to migrate northwards under the influence of longshore drift until again breached. A shallow, braided, sandy channel forms during low-flow conditions and the mouth may close. The mouth is typically closed for about 5% of the time.

The coastline south of the mouth consists of a Holocene beach backed by a stabilised dune which forms part of the river mouth barrier. Beaches are narrow and controlled by bedrock outcrops. This contrasts strongly with the coastline to the north, which is one of only three accretionary areas along the South African coastline. The prograding coastal zone has given rise to a beach ridge plain characterised by wide beaches which grade into a series of low, shore-parallel, aeolian sand dunes. The accretion process dates back to the earliest photographic records of 1937 and probably to 5 000 B.P. Recent records show that after 1937 there was an erosion period during the drought years of 1978-83 coinciding with a strong El Nino. Coastal retreats up to 11 m/yr were recorded. During 1957-1960, the end of the 1953-61 wet period, the process was reversed and progradation in excess of 30 m/yr was recorded.

There is relatively little industrial development in the catchment, where human activities are mainly agricultural and pastoral. There is consequently relatively little industrial pollution and the major anthropogenic effects on the river come about through water abstraction and the still controversial effects on rates of soil erosion.

The Thukela Shelf

The south-east African continental shelf is generally narrow, being about 12 km wide off Durban but widening to more than 45 km off the Thukela River (Figure 2). Much of this shelf is derived from sediments from the Thukela River. A feature of the shelf is a series of submerged aeolianite outcrops which represent submerged coastal dune cordons, formed during lower Pleistocene sea levels which were drowned during subsequent Holocene transgressions. The shelf break is at approximately 100 m depth.

The southern part of the shelf is dominated by terrigenous sediment; it has the thickest sediment accumulation and has extensive flat areas. The northern part of the shelf is more uneven with a greater proportion of reef areas. The influence of the Thukela River on the shelf is most apparent during summer rains via the silt plume. Slight salinity reductions can be detected offshore.

The most important oceanographic feature of the area is the southward flowing Agulhas current. This is a major western boundary current with a mean width of 100 km and speeds of > 2.5 $m.sec^{-1}$. Its depth has been traced to 2 500 m.

In assessing the potential effects of the dams on the coast and shelf it was realised that these could be modified or over-ridden by climatic changes. Wet and dry phases are products of prevailing climatic factors which have been shown to have major effects on the coastline north of the Thukela. A sea level rise of 20 cm is forecast in the next 35 years and 1.5 m in the next century. Available estimates indicate a consequent loss of 25 m of shoreline in the next 100 years. Projected climatic changes suggest that the local climate will become more dominated by tropical cyclonic weather. Changes in predominant wind patterns could reverse current conditions and foster accelerated erosion of the presently accreting beach zone. More cyclonic weather could however produce fewer swells, moving less sediment offshore and leaving it for fair weather waves to move it inshore, thereby favouring beach progradation.

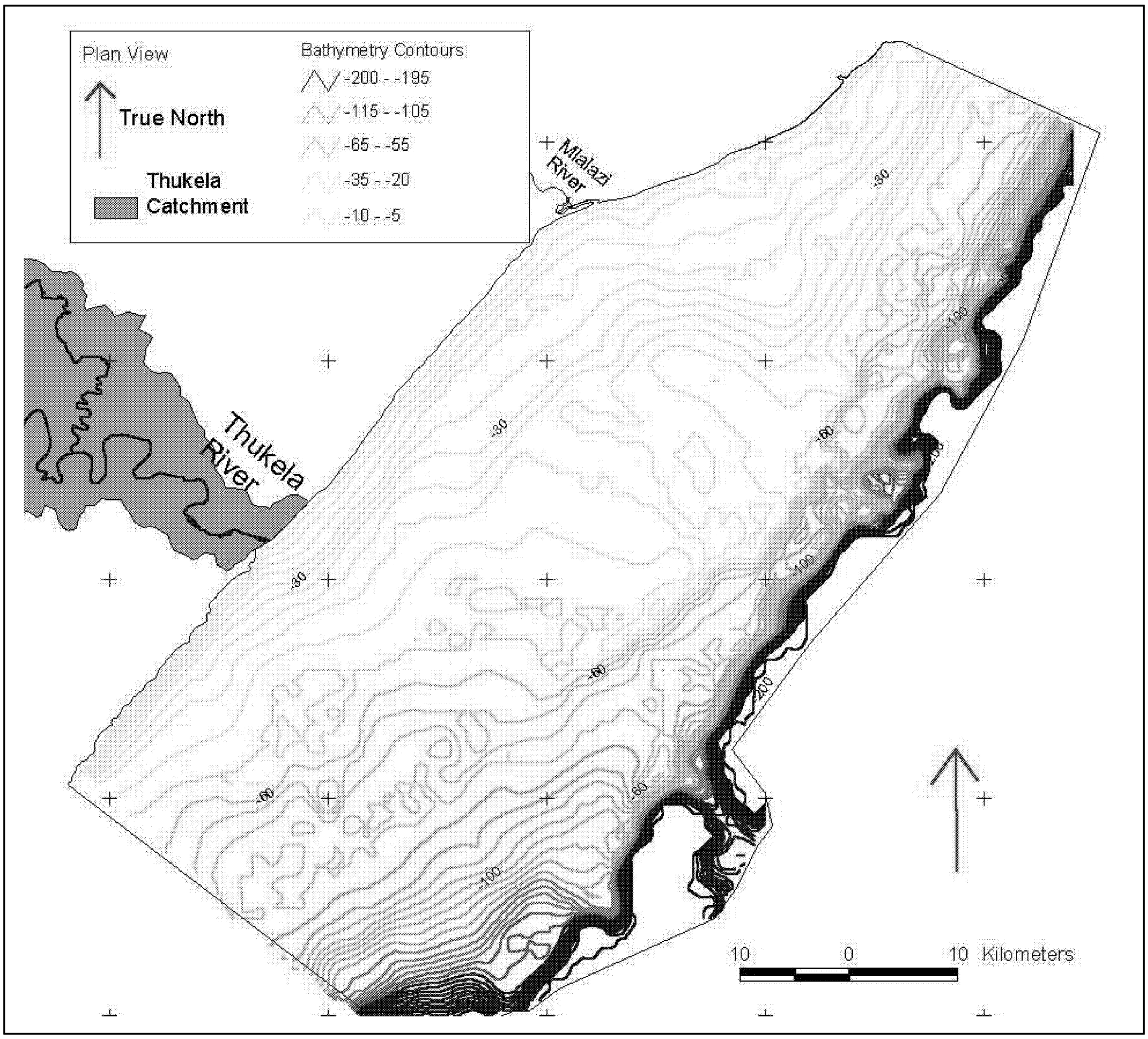

Figure 2. Bathymetry of the Thukela Bank.

Effects of the proposed dams on the coastal and shelf environments

Physical effects

The anticipated scenarios are as follows. Dam building will cause a short-term increase in the sediment load. In the longer term, however, the dams will affect the outflow and sediment input from 30% of the catchment. Floods will be attenuated and sediment output reduced. At the same time climatic change appears to be directed towards a slowing-down or halting of coastal progradation. Sediment retention by dams would accentuate this process.

It is expected that any dam-induced changes in the coastline will extend progressively northwards from the mouth and the effect(s) will be greater during dry phases than wet. Estimated distance and time scales indicate that effects in the area up to 13 km north of the Thukela mouth will be noticeable within 10 years and up to 30 km north within the next 50 years.

Effects on the shelf are less certain. The shelf-coastline system is in dynamic equilibrium and any changes in one component will be reflected in others. The following are two of the presently significant expected changes:

1. Muddy areas of the Bank are expected to grow at the expense of more sandy areas.
2. A sediment decrease will result in the exposure of more sub-tidal reef.

Ecological effects
An assessment and forecasting of these effects is being attempted on the basis of the anticipated geomorphological changes. As the study is ongoing only results available to date are summarised here.

The 20-45 km wide Thukela Bank and the adjoining coastline provide a unique environmental combination in the South African context as it is the only shelf area and prograding beach on the east coast of the country. The frequently turbid conditions associated with the output of the Thukela River and the extensive areas of muddy sediments contrast with much of the rest of the east coast where the continental shelf generally extends less than 12 km offshore and the water, especially to the north, is clear enough to support the country's only significant coral growth areas. The muddy sediments of the Bank are interspersed with the submerged aeolianite reef described earlier and the combination of the two habitats provides significant line fishing grounds and the only shallow water penaeid prawn trawling grounds in the country.

The sandy beaches to the north of the Thukela are likely to become coarser, favouring some benthic species but greater significance probably lies in the reduction of detrital inputs which are important in the generally oligotrophic conditions of the east coast of South Africa. The effects of reduced sandy beach productivity are difficult to predict.

The only rocky shores in the possible impact area lie south of the Thukela mouth. High densities of brown mussels *Perna perna* occur in the vicinity and concern has again been expressed that a reduction in the detrital input could adversely affect inter-tidal filterfeeders. The dependence of rocky-shore filter feeders on terrestrially derived detritus has been established elsewhere in the province. Both oysters and mussels are harvested but the extent of any impact and the possible economic consequences are uncertain.

Of potential significance to subtidal reef communities are the factors mentioned above plus possible reduced turbidity which could favour corals and greater primary productivity in the water column as well as from fixed algae. Line fisheries dependent largely on reef fish are locally important at present. Changes in fish community composition are possible with a shift away from turbid water species to those favouring clearer water. Greater water clarity would also favour diving activities, especially spearfishing. The likelihood of turbidity changes and the direction of change remain, however, as moot points.

The forecast increase in total area of soft sediments presumably would favour species associated with such habitats. It would be important to establish whether sustained input of fine sediments would be accompanied by inputs of nutrients and detritus as it appears that areas off the Amazon and the Fly River of Papua New Guinea rely heavily on riverine inputs. The prawn trawl fishery is associated with muddy sediments and it might be expected that an increase in the area of this type of habitat would favour these species and ultimately the fishery. It is not certain, however, that a simple increase in the type of physical habitat favoured by the prawns would result in an increase in numbers.

The pelagic system would be altered by any change in turbidity. Decreased turbidity would enhance phytoplankton production, assuming that nutrient levels remain adequate. Unfortunately there are no measures of the relative inputs of nutrients derived from the low levels of upwelling that occur in the region and that derive from riverine inputs.

Conclusions

An unresolved problem is centred around the relative importance of flood events and average seasonal flow levels. The contrast between MAR's and extreme flood events has been emphasised and it is clear that one major flood can discharge more water and transport more sediments than might be found in an average year. Data from the offshore prawn trawl fisheries show that catches rose and remained high for three years following the flood caused by Cyclone Domoina in January 1984.

As far as the coast is concerned, there is relatively little infrastructure development along the coast in the main impact area to the north of the Thukela mouth, although the prograding beaches and the backing dunes to the south of the Mlalazi River (Figure 2) are backed by superb examples of coastal dune vegetation succession from beach pioneers to climax dune forest.

At this stage, possible biotic responses to environmental changes resulting from changed sedimentation patterns on the coast and shelf can be surmised although, as mentioned above, the contrasts and relative significance of the effects of normal flows and flood events require clarification. Equally the comparative effects of the dams on normal flows and flood events requires clarification. Changed water flow patterns have been considered very largely in terms of associated sedimentological events and processes rather than in terms of transport of other materials or the input of fresh water *per se*. This emphasis can be justified on the basis of present knowledge which suggests that the river is not a significant source of pollutants for the coastal zone and that this situation should not change in the short term. This comes about largely because water storage in the Thukela catchment is intended for transfer and use in the Vaal River basin and the Johannesburg-Pretoria complex rather than in the Thukela basin where industrialisation is minimal in comparison.

The major unanswered question at this stage relates to the extent and significance of carbon and nutrient input into the coastal zone and the shelf system. Available information on primary production is very scanty, but indicates generally oligotrophic conditions both in estuaries and offshore. This again raises the question whether the dams will significantly affect average flows as well as flood events or whether flood events are of such a magnitude that the dams are of little consequence.

4.15 Water quality and nutrient fluxes within the Zambezi River system: a review

Lindah Mhlanga

Abstract

The water quality of the Upper Zambezi River is influenced by the Baroste Flood Plains and the Chobe Swamps that act as sediment traps such that the Zambezi River enters Lake Kariba as fairly clean water with a reduced sediment and nutrient load. DDT, metal and sewage contaminants have been detected in Lake Kariba but have not been assessed in the outflow. The outflow from Lake Kariba is richer in ionic composition than the Zambezi inflow. The mid-Zambezi tributaries, the Sengwa, Gwayi and Sanyati rivers, bring nutrient-rich water into the lake. The nutrients from these rivers are temporarily locked in the hypolimnion partly to be released into the Zambezi through turbine discharges. An estimated 5.2% of the phosphorus leaves the lake via the Zambezi. Orthophosphate, total phosphorus and nitrate-nitrogen losses from Lake Kariba are estimated to be 52,216 and 1,146 tonnes respectively. The Luangwa, Hunyani, Kafue and Musengezi rivers bring nutrient-rich water into the Zambezi and into Lake Cahora Bassa. Most nutrients and sediments are trapped within Lake Cahora Bassa. There is a need to determine how much of the nutrients are released into the Lower Zambezi and consequently into the sea. A routine monitoring programme is required to make a detailed assessment of nutrient fluxes between the Zambezi River catchment and the sea.

Introduction

The Zambezi River, one of Africa's four major rivers, originates from a swamp at 1,400 m altitude along the Zaire-Zambia border (Balon and Coche 1974) and covers a catchment area of 1.4×10^6 km^2 (Pinay 1988). It flows over a distance of 3,000 km, dropping in altitude from 1,400 m at its source in western Zambia to sea-level at its delta on the Indian Ocean coast, north of Beira in Mozambique (Masundire and Matiza 1995).

The Zambezi River basin is one of the most complex catchments in Africa and the most important watershed in southern Africa (Balek 1971; Balon and Coche 1974). The catchment spans eight countries and the proportion of the catchment is 18.3%, 2.8%, 7.7%, 11.4%, 1.2%, 2%, 15.9% and 40% in Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe respectively (Masundire and Matiza 1995).

The course of the Zambezi River is composed of three ecologically distinct zones, the Upper, Middle and Lower Zambezi (Balon and Coche 1974). The Upper Zambezi basin covers an area of 513,000 km^2 (excluding the Okavango system) through which the Zambezi meanders over 1,078 km between its headwaters in northern Zambia and Victoria Falls (Pinay 1988). The Middle Zambezi stretches 853 km from Victoria Falls to the Cahora Bassa dam in Mozambique and the Lower Zambezi covers the remaining 593 km to the Indian Ocean in Mozambique (Balon and Coche 1974). These sections are distinct geographical and biological entities (Masundire and Matiza 1995).

During its course, the Zambezi River crosses a number of flat plains and is interrupted by steep sections of rapids and falls. The middle course of the Zambezi River has been interrupted by two artificial impoundments: Lake Kariba and Lake Cahora Bassa, which are 5,364 km^2 and 2,739 km^2 respectively.

It is assumed that water quality and nutrient fluxes within the Middle Zambezi, especially Lake Kariba and Lake Cahora Bassa, affect processes further downstream and into the Indian Ocean - i.e. the Zambezi River is a pathway of dissolved and particulate materials between the Zambezi basin catchment and the Indian Ocean. However, information about its influence on marine resources on the Indian Ocean coast was not obtained. This review discusses the water quality of the Zambezi River including the influence of the tributaries on the water quality and the effect of the Zambezi River on the coast environment.

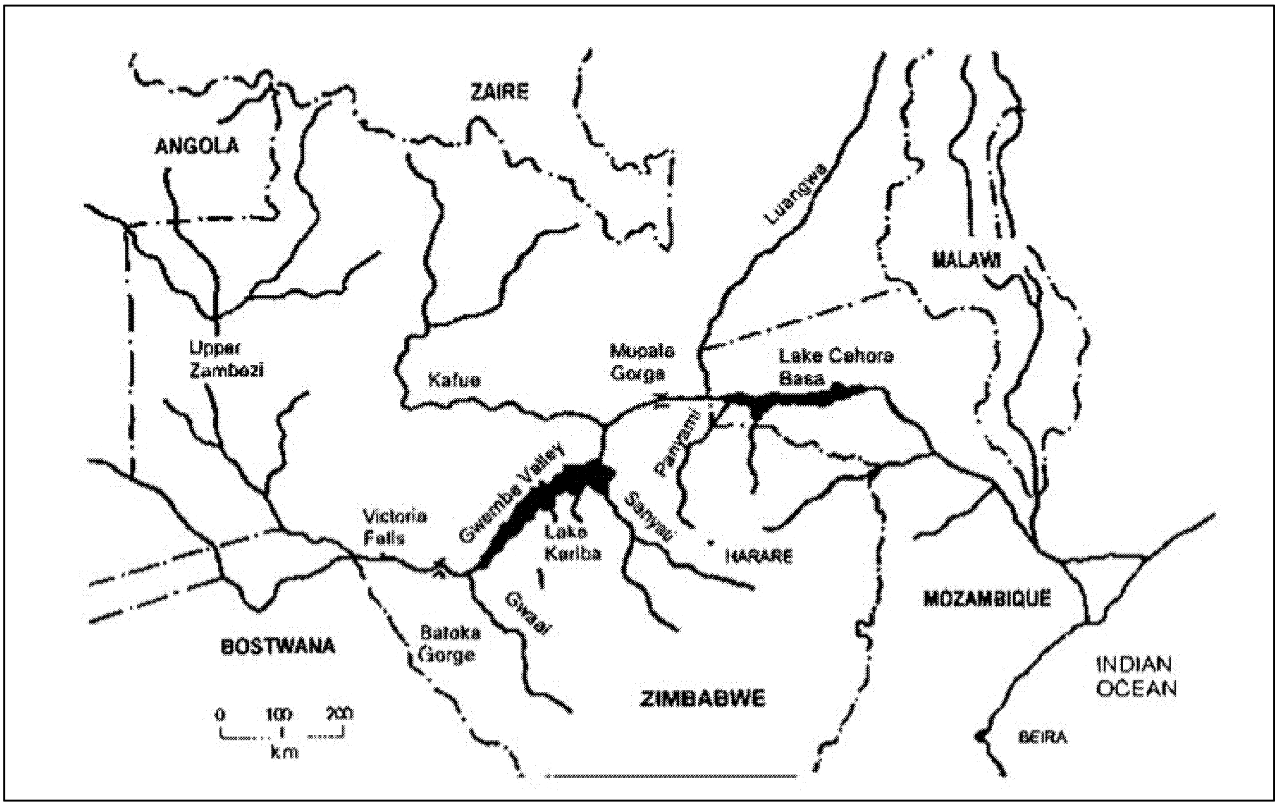

Figure 1. The Zambezi River.

Limnological characteristics of the Middle and Lower Zambezi

The physico-chemical status of the Middle and Lower Zambezi was assessed prior to the closure of the Cahora Bassa dam (Hall *et al.* 1977). An assessment in 1973 and 1974 showed that the water quality of the Middle Zambezi is mainly determined by the Kariba dam with the Kafue River, which enters the Zambezi below the Kariba dam (see Figure 1), playing a minor role (Hall *et al.* 1977). The concentration of dissolved metals in the Zambezi River was mainly determined by the outflow from Lake Kariba and in the Shire River.

Water quality of the Zambezi River from Chavuma to Luangwa has been monitored over three years (1995 to 1998) (Mukono 1998). The variation in physico-chemical parameters of the Zambezi River from Chavuma Falls (Upper Zambezi, Zambia) to Luangwa and Zambezi River confluence (on the border with Mozambique, just above Lake Cahora Bassa) is shown in Figure 2. Conductivity, turbidity and total dissolved solids levels were high between Chavuma Falls and the Lukulu River. This section falls within the northern highlands of Zambia. Conductivity, turbidity and total dissolved solids increased from 25μS, 5, and 5 mg/l to 215μS, 30 and 100 mg/l respectively between Chavuma Falls and Watopa. There is a notable decrease in these parameters as the river flows through the Barotse Flood Plains and the Chobe Swamps (Upper Zambezi). The Barotse Plain and the Chobe Swamps act as sediment traps (Balon and Coche 1994; Mukono 1998). The Barotse Flood Plains reduce the dissolved solids, conductivity and turbidity by 55%, 65% and 80% respectively (Mukono 1998). The silt load is reduced to relatively low levels before the river enters Lake Kariba.

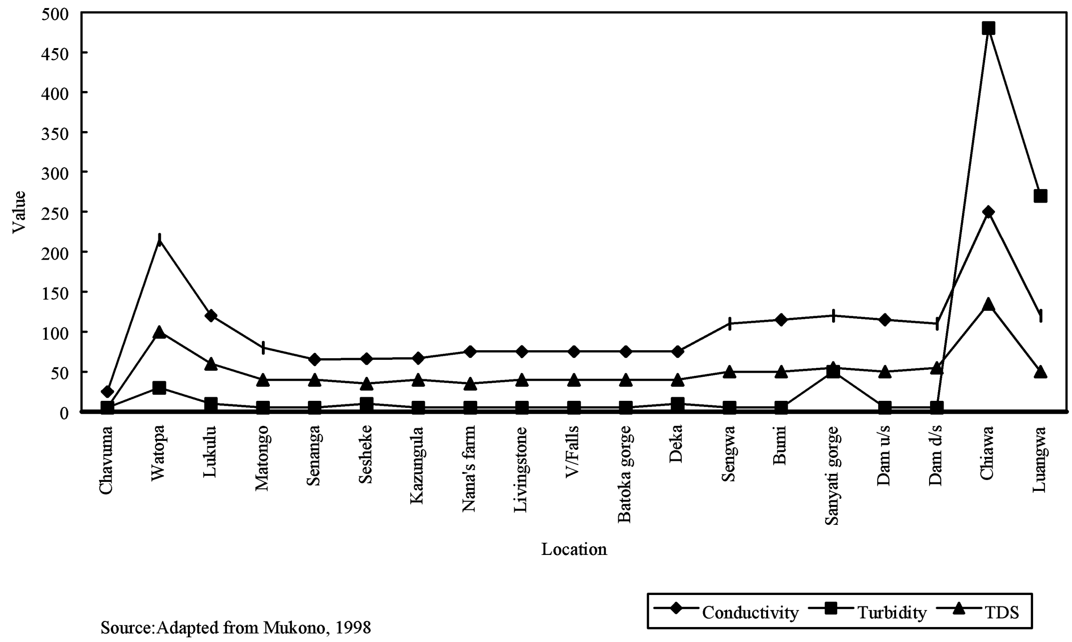

Figure 2. Variation in conductivity (µS), turbidity and total dissolved solids (mg/l) along the Zambezi River.

The values remain relatively constant between Matongo and Batoka Gorge (just downstream of Victoria Falls). The Zambezi River picks up mainly finer sand between the last sediment area (Chobe Swamps) and the lake because the geological formations comprises mainly of hard Batoka basalt (Balon and Coche 1974). A general increase of these parameters at river stations within Lake Kariba (Sengwa, Bumi and Sanyati Gorge) indicates the influence of the seasonal Middle Zambezi catchment rivers: the Sengwa, Gwayi and Sanyati rivers. The Sanyati River drains the upland Zimbabwe farmlands and brings down to Lake Kariba highly mineralized water (Balon and Coche 1974). Conductivity, total dissolved solids and turbidity are higher in the outflowing water than in the inflow.

The average outflowing water is proportionally richer in average ionic composition than the Zambezi River water entering the lake (Balon and Coche, 1974). Peak values were observed at Chiawa and Luangwa rivers before entering the Cahora Bassa dam.

Estimates of N and P inputs into Lake Kariba

The preliminary estimates of nitrates and orthophosphates inputs into the lake from rivers are 13.6$\mu g l^{-1}$ and 21.8$\mu g l^{-1}$ respectively (Magadza *et al.* 1986). After assuming the same values for the Zambezi River and an annual inflow of 47 km^3, nitrogen and phosphorus loading into the lake were estimated as 704 tonnes and 1,025 tonnes respectively (Magadza *et al.* 1986). The N:P ratio in the lake is 1:1.45. More phosphorus than nitrogen enters the lake. 5.2% of the phosphorus was estimated to leave via the Zambezi, 12.8% as harvested fish, 15% as particulate phosphorus while 67% is retained in the lake (Magadza *et al.* 1986).

The outflow from Lake Kariba was proportionally richer in calcium, potassium and fixed carbonates (Balon and Coche 1974). The lake enriches the original river water by ion exchange rather than by concentration and dilution (Balon and Coche 1974).

Nutrients in the Zambezi River below the Lake Kariba turbines

Magadza *et al.* (1986) made preliminary estimates of nitrates, phosphates and total phosphorus from Lake Kariba via the Zambezi. The estimates were based on preliminary data on phosphorus and nitrogen measurements in Lake Kariba in 1986. Nutrient losses via the Zambezi River were calculated from river flow data. A loss of approximately 52 tonnes of orthophosphate per annum was estimated. Through extrapolation using available data, total phosphorus losses were estimated at 216 tonnes per annum. The bulk of the total phosphorus is lost as particulate phosphorus in form of silt. An estimate of 1,146 tonnes of nitrate-nitrogen is lost via the Zambezi. The molar ratio loss of PO_4-P:N and T-P:N loss via the turbine discharge was estimated to be 1:51 and 1:12 respectively.

Lake Cahora Bassa

The Cahora Bassa dam, which has created Lake Cahora Bassa, the second largest reservoir on the Zambezi River, is located approximately 220 km downstream of the Kariba dam. 71% of the water in the lake is supplied by the Zambezi River and consists of water discharged from the Kariba dam while the Kafue and Luangwa rivers provide 10% and 18% respectively (Gliwicz 1984).

Activities upstream have a significant impact on the limnology of Lake Cahora Bassa, especially within the Lake Kariba catchment. Lake Kariba is the major source of orthophosphate to Lake Cahora Bassa (Hall *et al.* 1977). The outflow into the Zambezi from the turbines (at 485 m.a.s.l. average operating level) is drawn from around 20 m depth which is the hypolimnion of the lake (Coche 1968). Phosphates carried into Lake Kariba by the main tributaries are temporarily locked (trapped) in the hypolimnion. They become available at overturn at the end of July when they are released into the Zambezi. The discharge of hypolimnetic water from the dam increases the nutrient load of the river downstream (Begg 1973) and has been noted to produce a nutrient peak in Cahora Bassa (Hall *et al.* 1977). A recent assessment showed that discharged water below the Lake Kariba dam wall was richer in ammonia, nitrates and total nitrogen with concentrations of 72.3, 34.8 and 790.4 μgl^{-1} respectively. The concentrations of ammonia, nitatres and total nitrogen above the dam were 31.3, 4.8 and 748.5 μgl^{-1} respectively.

A survey in July 1994 assessed the water quality of Lake Cahora Bassa (Mandima 1997). Recurrent droughts between 1981 and 1992 led to reduced inflows in the dam. Nitrogen and phosphorus levels had both declined from the levels recorded in the 1970s and 1980s (Mandima 1997; Table 1).

Table 1. Concentration of chemicals recorded in Lake Cahora Bassa.

Chemical	1970s	1980s	1994
Nitrate-nitrogen μgl^{-1}	70	140	211.6
Ammonia μgl^{-1}	170	n.d	26.8
Orthophosphate μgl^{-1}	80	75	4.9
Total phosphorus μgl^{-1}	n.d	n.d	32.7

Source: Mandima 1997

This was attributed to reduced inflow of water to the lake during the severe droughts that affected the catchment area in the preceding decade. The mean concentrations of ammonia and total nitrogen in the dam were 26.8μgl^{-1} and 1 267μgl^{-1} respectively. Orthophosphate ranged from 2.0-9.5μgl^{-1}. Changes in nutrients reflect the impact of drought (Mandima 1997).

The decline in the eutrophic status affected planktonic organisms. Species abundance declined, except for *Bosmina longirostris* (Mandima 1997; Table 2). This could have also affected the marine fisheries.

Table 2. Abundance (number m^{-3}) of plankton species in Lake Cahora Bassa.

Zooplankton	1980s	1994
B. longirostris	1 423	3 172
Diaphanosoma (sp.)	2 827	513
Calanoida	6 560	707
Cyclopoida	17 998	422
Keratella	1 600	293

Source: Mandima 1997

Information on nutrient input and output in Lake Cahora Bassa would provide an idea of the nutrient contribution of the Zambezi to the marine environment.

Impact of the tributaries on the Zambezi River

The major tributary rivers that influence the chemistry of the Zambezi are the Luangwa, Hunyani, Musengezi, Shire and Kafue rivers. The Luangwa, Hunyani and Musengezi drain into Lake Cahora Bassa. Information available on the water quality of the tributaries is limited to the early years. Tributaries to the Zambezi bring nutrient-rich water. Hall *et al.* (1976) observed that the Zambezi entering Mozambique is richer in inorganic nutrients than the pre-Kariba Zambezi (Zimbabwe). The outflow from Kariba in 1965 had lower inorganic nutrients than the Zambezi entering Mozambique (Coche 1968). This indicated that the Kafue River contributed a considerable quantity of nutrients. Major tributaries feeding the Zambezi River pass through sites of extensive mining activities. The Kafue River drains the entire copper mining region of Zambia and the Mazowe River drains the mining operations in the Shamva region of Zimbabwe. There is however, limited information on the impacts of mining on water quality.

The Kafue River basin covers 152,000km^2. The Kafue River carries the outflow of the man-made Lake Kafue. It is a major tributary that enters the middle Zambezi between Kariba and Cahora Bassa and it contributes 12% of basin flow at its confluence with the Zambezi River (Kasimona and Makwaya 1995). There are major industrial towns and centres located along the Kafue River.

The Luangwa river basin covers 165 000 km^2 and contributes 500 cumecs as mean annual run-off to the Zambezi basin at its confluence with the Zambezi (Kasimona and Makwaya 1995). Luangwa River joins the Zambezi just upstream of Lake Cahora Bassa. It contributes an estimated mean yearly sediment load of 8 million tonnes and is characterised by high turbidity and high sediment load that influences the water at its confluence with the Zambezi (Kasimona and Makwaya, 1995). Hall *et al.* (1977) noted that the Luangwa River is poor in ions than Zambezi and consequently it does not appreciably affect the chemical composition of the Zambezi main stream. However, in flood the Luangwa carries a heavy silt load that dramatically changes the transparency of the Zambezi (Hall *et al.* 1977).

Lower Zambezi

The lower section of the Zambezi is from Cahora Bassa rapids to the delta on the Indian Ocean coast in Mozambique. The Shire River joins the Zambezi about 150 km from the delta. Land use activities carried upstream have a direct impact on the lower section. Although information may be available, none was obtained regarding the impact of water quality and nutrient fluxes on the ecology of the Zambezi delta.

The Shire River is another major tributary of the Zambezi. It joins the Zambezi downstream from the dam wall about 150 km from the sea. Shire is extremely rich in inorganic nutrients and exerts a considerable effect upon the Zambezi below their confluence (Davies *et al.* 1975). While information on the current physico-chemical status of Shire was not obtained, it is apparent that there has been an increase in its nutrient content as evidenced by the invasion of water hyacinth in Lake Malawi. Most of the dissolved salts transported by the Shire originate from Lake Malawi (Jackson *et al.* 1976) but some of the nutrients particularly phosphate and nitrate are also contributed by the soil of the section of the valley in Mozambique which is intensively farmed (Davies *et al.* 1975). The Shire has a significant influence on the chemistry of the Zambezi (Hall *et al.* 1977) and is the most important tributary of the Zambezi in Mozambique. Its water has a tremendous impact upon the chemistry of the Zambezi River water. It establishes a different nutrient regime downstream from its confluence with the Zambezi.

The Hunyani and Musengezi rivers drain agriculturally and industrially developed parts of Zimbabwe. They consequently contribute appreciable quantities of nutrients to the Zambezi. Assessments in 1974 (Hall *et al.* 1977) showed that Hunyani and Musengezi had conductivities of 350 μScm^{-1} and 506 μScm^{-1} respectively. Hunyani water was richer in bicarbonate, chloride, ammonia, nitrate, sodium and magnesium than the Zambezi water. Large concentrates of sodium, potassium, calcium, magnesium and phosphate occurred in Musengezi River.

The Zambezi delta which is rich in mangrove vegetation supports marine aquatic resources; fish shrimps, prawns and other sea resources. The ecosystem has been subjected to deforestation at a rate of 2.4% from 1972 to 1990 (SARDC CEP Factsheet 1998). Mangroves have been extensively cut for poles for construction of houses, firewood and timber for boats while their leaves are used for animal fodder. The impact of environmental degradation on marine fisheries and other marine resources has not been assessed.

Discussion and Conclusion

The water quality and nutrient fluxes to the Zambezi River has been described in a generalised way because there is a general lack of information on nutrient losses from point and non-point sources. The information available is limited to objectives of specific studies. A detailed assessment of nutrient loads to the Zambezi (including Lake Kariba and Cahora Bassa dam) and the sea requires data on nutrient concentrations from major tributaries and hydrological data on water flow to the main river and the two lakes. The Zambezi River Authority is in the process of establishing a monitoring programme. This will be confined to the part of the Zambezi commonly shared by Zimbabwe and Zambia which comprises mainly the Upper and part of the Middle Zambezi up to Luangwa. To have a clearer picture of nutrient fluxes within the whole river system it may be necessary to include the lower Zambezi. This will enable impact assessment of upstream activities on the marine environment.

There are also monitoring programmes being carried out that will enable more detailed assessment of nutrient fluxes within the Zambezi River System. For example, the Environmental Council of Zambia is monitoring nutrient loads in the Lower Kafue.

The major environmental problems within the Zambezi valley that may affect nutrient fluxes to the sea include:

- Environmental degradation through unsustainable and destructive land and water use patterns.
- Poor watershed management, sewage and industrial pollution, drainage of wetland and water abstraction
- Flood regulation
- Rapid population growth which is currently estimated at 3% per year
- Deforestation resulting in increased soil erosion, sedimentation, siltation and siltation induced flooding
- High rates of urbanisation and industrial activity affecting water quality in the basin.

Lack of data makes quantification of nutrient fluxes from the river to the ocean difficult. Surveys are needed in the three ecological zones of the river in order to assess nutrient fluxes to the ocean, determine variations and assess the impact of the dams. The two dams on the Zambezi act as silt traps (Davies *et al.* 1975; Balon and Coche 1974). The estuary and delta area have both experienced a general decrease in the amount of silt reaching them (Davies *et al.* 1975). Such a decline in silt load may allow the incursion of the sea into the delta where normal sea erosion will no longer be countered by floodwater deposition of silt from the now regulated river. The major environmental concerns for the coastal zone are the impacts on the shrimp industry and on the mangroves.

In order to understand the effects of human-induced activities of the Zambezi River on the Indian coast there is need to generate relevant data. At present there is relatively little scientific information on the impact of the Zambezi on the seacoast. Investigations can be carried-out to generate data on:

- Effects of upstream impoundments and flood regulation on the Mozambique coast since the river has many artificial impoundments
- Impact of the cessation of silt transport to the Mozambique coast
- Impacts of the Zambezi basin dams on the shrimp industry of Mozambique at the Zambezi delta.

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4.16 Human impact on groundwater quality along the Kenyan coast: A case study on an unconfined aquifer to the north of the coastal town of Malindi, Kilifi District, Kenya

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Abstract
Potable water is a scarce resource in the coastal parts of Kenya. Most of the water used in the larger coastal towns originates from inland sources. Mombasa, the largest city along the coast, gets most of its water from the Mzima springs, on the slopes of Mt Kilimanjaro. The waters from the inland sources are inadequate and are supplemented by groundwater. Most of the groundwater aquifers yield either saline or brackish water, and the few freshwater aquifers are currently in danger of being over-extracted or polluted. Studies are underway for ways to utilise the groundwater resources along the Kenya coast in a sustainable manner.

There are two types of aquifer along the coast, confined and unconfined aquifers. The area studied is a N-S oriented unconfined aquifer. It is in a V-shaped, clayey lagoonal depression bordered by Pleistocene sands on the west and Recent dune sands on the east. The freshwater aquifer in the area is the main source of potable water for the urban centres of Gongoni and Timboni and the main Mombasa Salt Works processing plant. The aim of the study was to look at the impact of sand harvesting, and possible saline contamination of the aquifer by activities at the nearby salt harvesting plant and by seawater intrusion. The major factor abetting pollution of the freshwater aquifer is the sand harvesting activity which exposes the aquifer to the atmosphere. Extension of the salt works closer to the aquifer field combined with high abstraction rates may also lead to saline water intrusion and contamination of the aquifer.

Key words: Freshwater aquifer - Sand harvesting - Salt harvesting - Pollution

Introduction

In developing countries, untreated water is the most commonly-encountered health threat and still causes an estimated 25,000 deaths a day - either because infected water is directly consumed or because its use leads indirectly to infection from vector-borne diseases such as malaria and bilharzia (UNEP/GEMS 1991). Water pollution in these countries has been accelerated by industrialisation and urbanisation, accompanied by poor waste treatment practices.

Today, over 300 million people in Africa do not have reasonable access to safe water, and even more lack adequate sanitation (UNEP 1999a). In addition, an estimated 80% of all diseases and over one third of all deaths in developing countries are caused by contaminated water and, on average, as much as one tenth of each person's productive time is sacrificed to water- related diseases (UNEP 1999a).

Most of the groundwater aquifers along the coast (confined and unconfined) are either saline or brackish. The few freshwater aquifers are now in danger of being over-extracted or polluted due to a number of factors, including urbanisation and the consequent increase in population, intensification of agriculture (particularly in watershed areas) and industrial growth. Due to the scarcity of fresh groundwater resources at the coast, most of the water used in the larger coastal towns originates from inland sources. Mombasa, the largest city along the coast, gets most of its water from the Mzima springs, on the slopes of Mt Kilimanjaro. This supply is inadequate and is supplemented by coastal freshwater aquifers. In most of the smaller towns along the coast, communities depend almost entirely on water from largely unconfined aquifers. Studies are therefore underway to look at ways and means of utilising the groundwater resources along the Kenya coast in a manner that:

1) is sustainable over the long term, and protects the resource;
2) maximises water-related benefits for the majority of people in a particular area;
3) addresses all significant human and ecosystem water needs; and
4) ensures the participation of all relevant parties in the water allocation process and at the appropriate level (UNEP 1999b).

Brief review of coastal geology: Kilifi district

The rocks in the Kilifi district are characterised by sedimentary rocks ranging in age from the Permo-Triassic Duruma rocks comprised of Taru, Maji-Ya-Jumvi, Mariakani and Mazeras sandstones, the Jurassic-Cretaceous rocks represented by the Kambe limestones, the Tertiary rocks of the Baratumu, Marafa and Magarini formations consisting of sandstone intercalated with limestone and shale beds, with the youngest Magarini Formation composed of red unconsolidated sand rich in ferrous minerals. The Pleistocene rocks consisting of coral reefs and detrital sediments mark the upper end of the lithified sedimentary rocks in the area. All these formations dip gently eastwards and become progressively younger towards the coast (Figure 1).

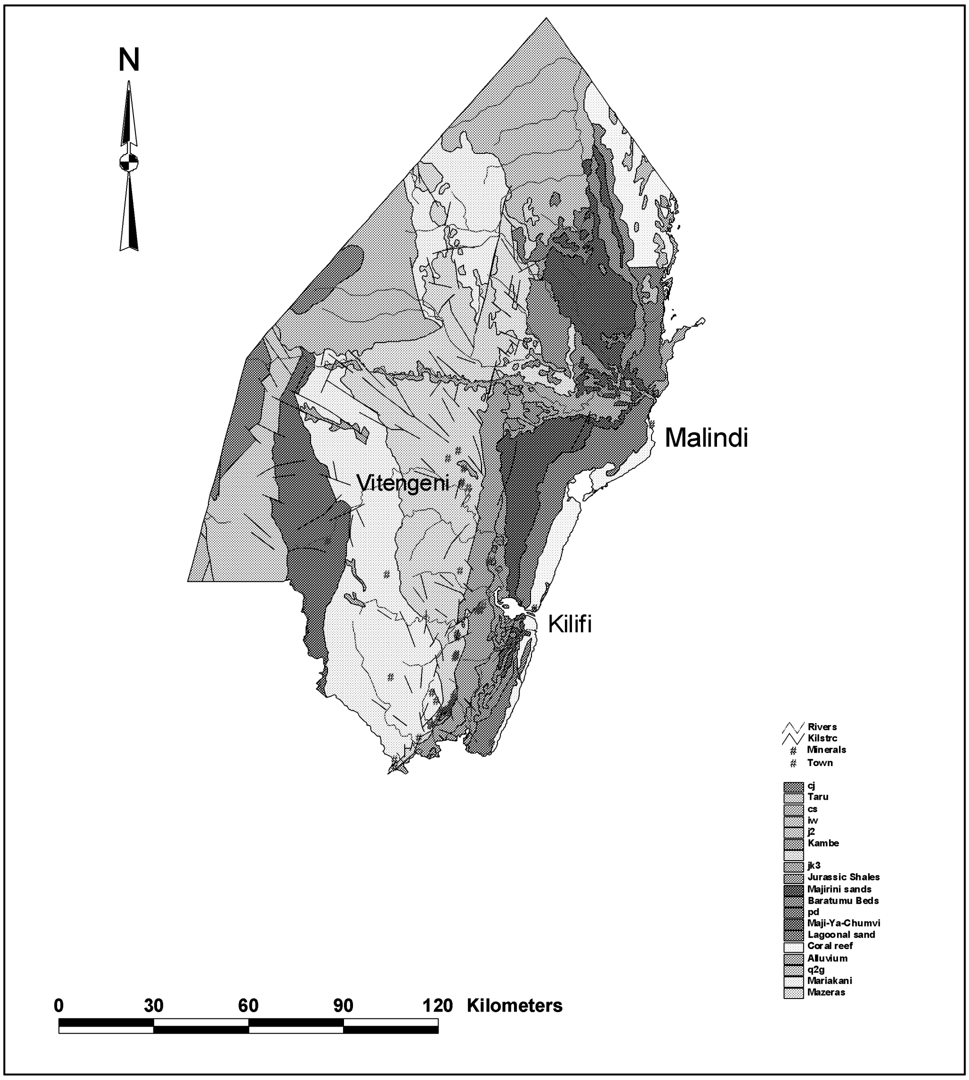

Figure 1. Geology of Kilifi district.

Geochemical analysis of soil and water samples indicate that the chemical composition of the soils and water in the area is greatly influenced by the mineralisation (JICA and MMAJ 1993) so that mineralisation and water quality are related. The largest mineral deposits of the area occur in the Kinangoni and Vitengeni areas and are predominantly of argentiferous galena with marcasite, sphalerite, barite, chalcopyrite and arsenopyrite (Bugg 1982). Because the mineralization is to a large extent structurally controlled, and to a very large extent may have great impact in areas adjacent to the fault lines, the groundwater generally contains high levels of lead, zinc, copper and mercury. Therefore groundwater quality varies within the area

(Ongweny 1975) and boreholes are drilled without considering the geological structure and hydrogeochemistry of the area. This has had serious consequences. A lot of money has been spent to drill boreholes, but most of the boreholes contain poor quality water and are subsequently abandoned. There is also growing concern about pollution of groundwater from the recharge areas upcountry. The rivers are becoming more vulnerable to contamination from human activities such as mineral mining and waste disposal from developed centres upcountry (Davies 1994).

Waterways in Kilifi District

Several large rivers drain into the Indian Ocean from the interior, for example the Tana and Sabaki rivers (Figure 2). These rivers undoubtedly recharge some of the coastal unconfined aquifers as they cut through the coastal plain sands before emptying into the Indian Ocean, particularly during high flood periods. No scientific investigations have, however, been carried out to examine the relationship between the fluvial inputs and unconfined groundwater aquifer recharge along the coastal zone.

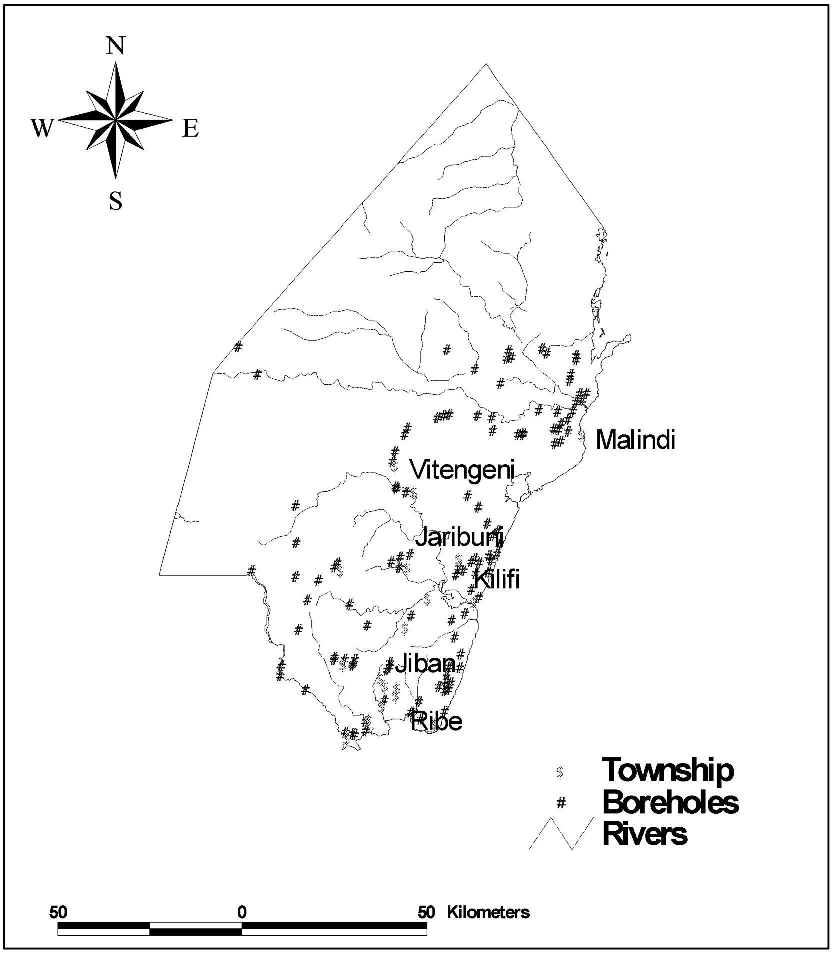

Figure 2. Waterways of Kilifi district.

The Kenyan hinterland is becoming increasingly populated, and settlements, as well as agricultural and small-scale industrial activities (and related deforestation) are fast expanding along the formerly pristine river valleys. These have resulted in increased sediment load in the rivers draining to the sea, which can degrade the water quality, storativity and transmissivity of a freshwater aquifer, pollutants from increasing use of agricultural fertilisers, raw domestic and industrial sewage could pose a serious threat to such fluvial-linked unconfined aquifers in the long term.

Some large urban centres such as Nairobi and its suburbs are in areas with numerous waterways which eventually discharge into the larger rivers that drain into the ocean. Nairobi is already a major source of pollution, and the Nairobi River, which drains into the Athi River east of Nairobi, is now virtually devoid of fish and macro-invertebrates and has high concentrations of faecal coliform, heavy metals, organochlorine pesticides, and solid waste amongst a myriad of other pollutants. Traces of some of these pollutants, particularly the persistent organic pollutants, may reach the ocean despite flushing/dilution by other relatively clean tributaries and natural processes of in-river degradation or sediment absorption, and affect the quality of coastal unconfined freshwater aquifers.

Where the near-surface, unconfined aquifers are far removed from fluvial sources and influences, the major recharge is from direct precipitation. The amount and quality of water retained in such aquifers is critically balanced between the prevailing climate/rainfall regime, geology and structures, the size of the recharge area, type of land cover, anthropogenic activities within the recharge area and abstraction demand.

The study area

Gongoni-Fundi-Issa-Timboni is a N-S oriented, V-shaped, flat, lagoonal depression lying in the coastal plain of Kenya at an altitude less than 45 m a.s.l. It is characterised by clays, and is bordered by Pleistocene sands on the west and Recent dune sands on the east (Figure 3). The average annual rainfall is *ca.* 850 mm/yr (Survey of Kenya 1977).

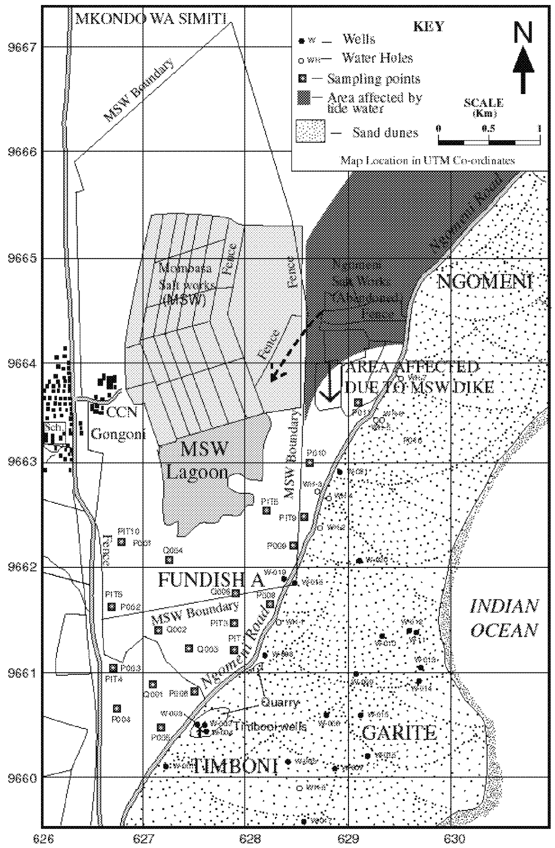

Figure 3. The study area.

Because it lies more or less at sea level, the lagoonal depression experiences daily incursions of seawater during high tide in the north-eastern sector (Figure 3). The lagoon typically ponds in most sectors following heavy rains, but generally dries out during the dry season. Consequently, it can be regarded as a seasonal swamp. Vegetation is mainly grassland/bushland, with negligible tree cover.

There are numerous water points dotted along Ngomeni Road which marks the boundary between the dune system to the east and the lagoonal depression to the west (Figure 3). The Timboni wellfield (Figure 3), located at a sand quarry near the road, is the main water supply source in the entire Gongoni area. Well W003, which is equipped with a diesel pump, was found flooded and not in use. The well currently in use is W002. Another major well located along the road is W018. This well belongs to Mombasa Salt Works

Limited and is equipped with a diesel pump. A majority of the water points along the road are shallow and are poorly protected.

Sand quarries have been developed along the line of potable groundwater supply, posing a serious threat to its quality. In addition, Mombasa Salt Works Ltd., which carries out its salt harvesting activities in the lagoonal area (largely restricted to the north-west part of the lagoonal depression) intend to expand their facility towards the line of springs along Ngomeni Road, sharply raising the possibility of salt water contamination of the freshwater aquifer(s). The aim of the study was to evaluate the possible impacts of continued sand harvesting and extension of the salt harvesting works on the quality of the potable groundwater aquifer within the area, and included: geological and soils studies, geophysical studies, and hydrogeological and water quality studies.

Materials and methods

1. Geological survey

The area is underlain by soils and unconsolidated sands, with no bedrock exposure. The geological survey therefore focused on mapping and determination of the sand dune morphology, sedimentology, structure and interface with the lagoonal clays.

2. Soil survey

Soil samples were collected by auger and from excavation pit profiles within a gridded spatial network at intervals of 500m, with higher sampling density in areas of particular interest (close to the spring line) (Figure 3). Laboratory analysis included particle size analysis, plasticity and dry bulk density measurements. Chemical analyses determined soil pH, organic carbon content, concentrations of the major cations Mg, K, Na, and Ca and cation exchange capacities of the soils.

3. Geophysical survey

The geophysical investigations consisted entirely of vertical electrical soundings (VES) conducted along three profiles using a SYSCAL R2 signal averaging terrameter with Schlumberger electrode configuration. In the dune area, other soundings were performed using an ABEM 300B terrameter. A maximum current electrode spacing of 100m was used.

4. Hydrogeology and groundwater quality survey

The hydrogeological studies involved elevation measurements of water points and test pits using a theodolite; assessment of groundwater quality; and assessment of the water balance. The water points were mapped with the aid of a Geographical Position System (GARMIN GPS 12XL model). The hydraulic properties of the aquifer were determined from pump tests which were conducted at the existing main Timboni well W002 and at well W018 belonging to Mombasa Salt Works Ltd. The pump test data were analysed using the Cooper-Jacob solution method to non-equilibrium equations because only one observation well is required, assumptions of the steady state of flow are not necessary, storativity value can be obtained, and the pumping period does not have to be long.

Waters from the existing water points were analysed for electrical conductivity (Ec), pH, total dissolved solids (TDS), temperature, Cl, Ca and Mg. Selected wells were also sampled for bacteriological analysis. Ec, TDS, and temperature measurements were determined using a HACH conductivity meter model 44600-00. Chloride was measured by both titrimetric and paqualab methods, while cations were determined by titrimetric methods. Bacteriological analysis of faecal coliform and total coliform counts was carried out by membrane and fermentation methods.

Geology and soils

1. Pleistocene and Recent dunes and sands

The very low degree of soil formation on the dune sands, which border the lagoon on the east, reflects their Recent origin. The dunes generally have heights greater than 30 m, are aligned parallel to the coastline and consist mostly of white or creamy coloured unconsolidated sands (Thompson 1956). The sands are derived mainly from detritus transported from the interior by the Sabaki River, which drains into the Indian Ocean south of the study area. The dune formation north of the Sabaki River mouth is controlled by the south-east monsoon winds and the northward flow of long-shore currents (Thompson 1956). The Pleistocene sands which border the study area to the west are believed to have accumulated as lagoonal sands (Caswell 1953; Thompson 1956).

2. Soils

(a) Spatial distribution

The soils are thickest in the northern sector (up to 250 cm) and thin toward the south (110 cm). The A horizon of soils in the area (10 to 32 cm thick) consists mainly of black organic clay/brown organic clay (with mineralised organic matter) (Figure 4). In the extreme eastern sector, bordering the sand dunes, the A horizon consists of a complex inter-fingering of organic clays, sandy clays, clayey sands and mineral clays. Excavation by Mombasa Salt Works in the western sector has exposed grey-brown clays, representing the B horizon (30 to 70 cm thick) at the surface.

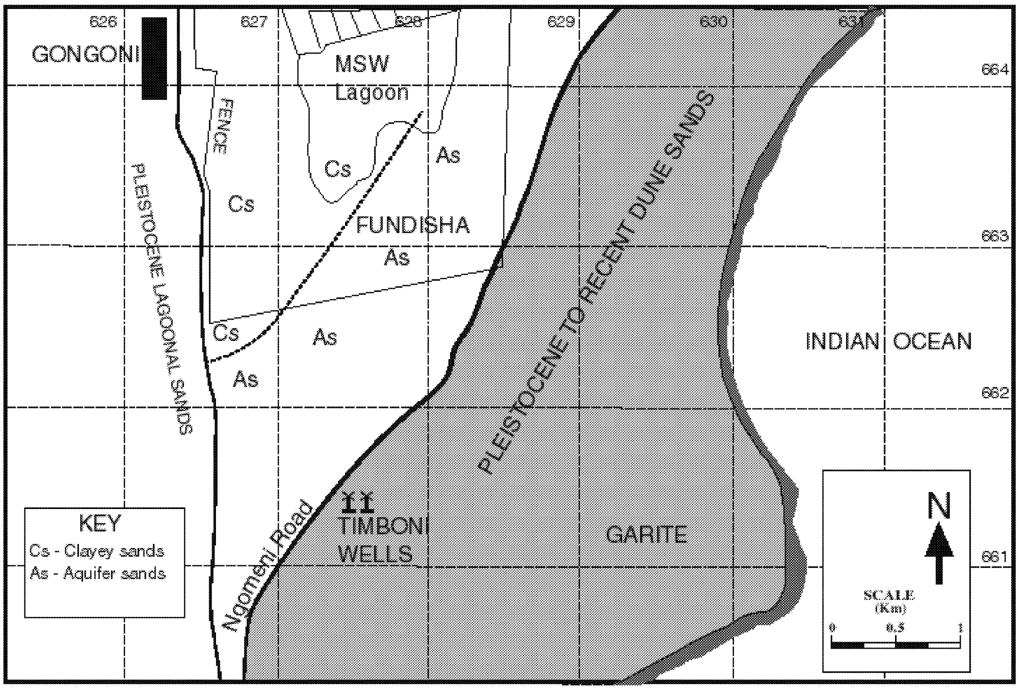

Figure 4. Spatial distribution of the A-horizon.

At greater depths, sandy clays are dominant in the southern sector, while clayey sands dominate in the western sector, although there are pockets of light-grey clays. In the eastern and southern sectors, aquifer sands occur between 130 and 160 cm. In the western sector, no aquifer was encountered after excavation to 250 cm. These results suggest that the inferred contact between the aquifer sands (sand dunes) in the east and the clayey sands in the west dips steeply westwards.

(b) Drainage characteristics

Salinization appears to be a problem in the north-east sector, where plants show evidence of injury. This may be due to both the expansion of the Mombasa Salt Works and to increased withdrawal of groundwater (Wicks and Herman 1995). Subsurface drainage is, however, probably enhanced by desiccation cracks which develop from the alternating dry and wet seasonal climate and extend to a depth of at least 50 cm below the surface. In addition, vertical and lateral interfingering of clays and sands are observed in this area. These two factors may have formed an expansive lateral network of interconnected conduits (micro-fractures) with relatively high permeability within the generally impermeable clays. The lateral extent of micro-fractures may explain the effects of salinization, which are related to the proximity of the sea-water inlet and artificial salt lagoons to the west. Although the waters in the aquifer sands underlying the soils in the lagoonal depression are saline, there appears to be little or no up-draw of cations from the lower to the upper parts of the soil profile (see below), ruling out significant top-soil salinization by upward capillary movement. In addition, as the configuration of the saline - freshwater mixing zone and the location of the halocline are functions of the porosity and permeability distribution of the aquifer (Wicks and Herman 1995), the inter-fingered clay/sand lenses in this area may have shifted the position of the mixing zone in the aquifer higher relative to the rest of the aquifer, resulting in increased salinization.

(c) Properties

The texture of the clays is fairly uniform throughout the area and tends to become more silty and sandy with depth (Table 1a and 1b). The underlying aquifer sands are strongly dominated by sand-sized quartz grains. They are normally distributed except for PIT 2 sand which has a positively-skewed grain size distribution.

Table 1a. Texture of the clays.

	Sample Number	% Sand	% Silt	% Clay	Texture Grade
1.	P001, 45-50cm	68	6	25	Sandy clay loam
2.	P004, 45-50cm	42	10	48	Clay
3.	P005, 45-50cm	40	12	48	Clay
4.	P006, 45-50cm	40	12	48	Clay
5.	PIT 1, 55-60cm	54	6	40	Sandy clay
6.	PIT 1, 80-85cm	62	8	30	Sandy clay loam
7.	PIT 3, 45-50cm	22	14	64	Clay
8.	PIT 3, 90-95cm	30	20	50	Clay
9.	PIT 4, 40-45cm	28	16	56	Clay
10.	PIT 4, 70-75cm	72	8	20	Sandy clay loam/sandy loam
11.	PIT 5, 45-50cm	28	12	60	Clay
12.	PIT 5, 80-85cm	40	16	44	Clay
13.	PIT 6, 40-45cm	40	16	44	Clay
14.	PIT 5, 90-95cm	74	8	18	Sandy loam
15.	PIT 7, 50-55cm	28	14	58	Clay
16.	PIT 7, 120-125cm	76	6	18	Sandy loam
17.	PIT 8, 95-00cm	48	26	26	Sandy clay loam

Table 1b. Texture of the aquifer sands

Phi value	**Aquifer sands %**					**Texture grade**
	PIT 1	PIT 2	PIT 4	PIT 9	Timboni	
0	7.74	3.98	17.56	1.68	7.28	Gravels + very coarse sand
1	19.89	84.15	15.90	20.27	9.90	Coarse sand
2	36.87	10.79	33.37	61.42	61.55	Medium sand
3	22.10	0.08	21.70	16.26	16.65	Fine sand
4	7.69	0.02	6.80	0.58	2.70	Very fine sand
5	2.68	0.03	3.99	0.07	0.94	Silt and clay

The clays are extremely plastic and fairly cohesive (M.M. Ndege, unpublished data). They have dry bulk densities ranging between 1250 and 1500 kg/m^3, which is characteristic of clays with low organic carbon contents (Table 2). The pH values in the upper portion of the clay strata are in the alkaline range and decrease with depth. They reflect the relatively high concentration of bases as compared to the deeper clay strata (Table 2). The low cation exchange capacities of the clays suggests that they are probably dominated by kaolinite-halloysite (or other types of 1:1 structured clays) with some hydroxides of Fe and Al (Kenya Soil Survey 1987; Brady 1990), suggesting that the major cations in the acidic clays immediately overlying the aquifer sands are probably Al^{3+} and Fe^{3+}.

Table 2. Physical and chemical characteristics of the clays.

Sample No.	Sample ID (cm	Org. C (%)	Dry density kg/m^3	C.E.C. me/100g	Mg ppm	K ppm	Na ppm	Ca ppm
PIT 1								
1	50-60	1.23	1330	11.76	221.31	320.64	936.00	2300
2	80-85	2.01	1320	8.40	63.23	N.D.	335.40	460
PIT 3								
3	45-50	1.35	1250	20.16	502.21	156.31	296.40	1035
4	90-95	3.64	1350	18.48	447.49	78.16	234.00	2415
PIT 4								
5	40-45	1.63	1420	11.62	470.59	3653.29	421.20	1265
6	115-120	1.61	1470	10.78	177.54	400.80	156.00	690
PIT 5								
7	45-50	2.61	1360	24.78	68.10	1372.74	514.80	1495
8	80-85	2.91	1490	21.56	68.10	1474.94	475.80	1840
9	140-145	1.85	1500	9.52	149.57	182.36	140.40	460
PIT 6								
10	40-45	2.44	1440	17.36	72.96	3356.70	280.70	690
11	55-60	2.71	1390	23.94	72.96	5482.94	280.80	460
PIT 7								
12	50-55	3.09	1380	17.64	390.34	1250.50	148.2	1035
13	120-125	2.52	1460	12.32	176.32	192.38	218.40	1035
PIT 8								
14	50-55	2.08	1340	15.68	150.78	266.53	171.60	575
15	95-100	1.89	1390	17.08	390.34	899.80	530.40	575

Geophysical studies

The aim of the geophysical investigation was to delineate the salt/fresh water boundary between: 1) the saline aquifer underlying the lagoonal depression and the freshwater aquifer; and 2) the freshwater aquifer and saltwater incursion from the Indian Ocean. Three VES profiles (Figure 5) were run with a maximum current electrode spacing of 100 m. In addition, two soundings were performed close to the beach on the eastern side of the dune sands.

The profile across the lagoon area (Profile A, Figure 6a) is characterised by very low resistivities with values of about 3 ohm-m close to the surface, decreasing with spacing to less than 1 ohm-m at a spacing of 100 m. These resistivities represent a fairly thick saline clay layer which may be sandy in places. This suggests that the possibilities of surface salt water leaking deep into the subsurface is minimal. Surface and near-surface materials in the dune area, which is topographically slightly higher relative to the lagoon area, are characterised by high resistivities, ranging between 1000 and 5000 ohm-m, consistent with expected values for dry sands. The aquifer depth increases from about 1.6m near the road to 6m about 400m from the road. This variation may be due to the increasing height of the measurement point on the dunes rather than a change in water table height. The aquifer under the dune has a resistivity of about 30 ohm-m, and its thickness varies from about 6 m at the spring line to an estimated 10 m at a distance of 500 m east of the

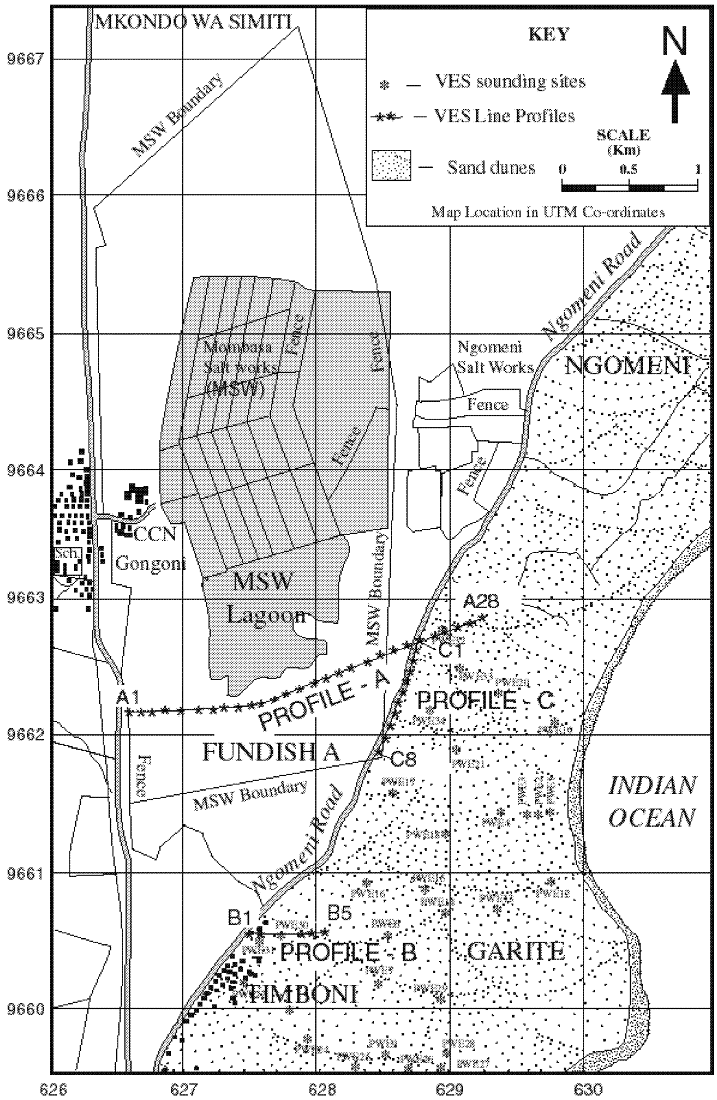

Figure 5. Study area showing VES profiles and sounding sites.

spring line. The exact bottom of the freshwater body could not be established due to the scatter of data in this depth range over the dune.

Profile B, which passes through the Timboni wells (Figure 5) shows similar characteristics to those of Profile A. The aquifer depth on the dune sands east of the Timboni wells is about 6 m (Figure 6b). Within the wells the saline layer is at a depth of 20 m. Within the dune area, but east of the wells, the saline layer could not be defined because of data scatter. Additional soundings conducted using an ABEM Terrameter did not resolve the data scatter problem, which made it difficult to better estimate the exact bottom of the freshwater body. However, based on the results from Profile A (where the aquifer thickness is between 6 and 10m at about 500m east of the spring line and within the dune area), it was inferred that the freshwater aquifer along Profile B has a maximum thickness of 10 m.

Profile C, taken along the Ngomeni-Timboni road (Figure 5), clearly delineated the freshwater/saline water boundary. The aquifer thickness along the line of springs was found to be 6 m thick with a resistivity of about 30 ohm-m (Figure 6c). The salt water, which occurred at a depth of 7 metres, had very low resistivities of 1-2 ohm-m. These values are similar to those obtained under the lagoon area.

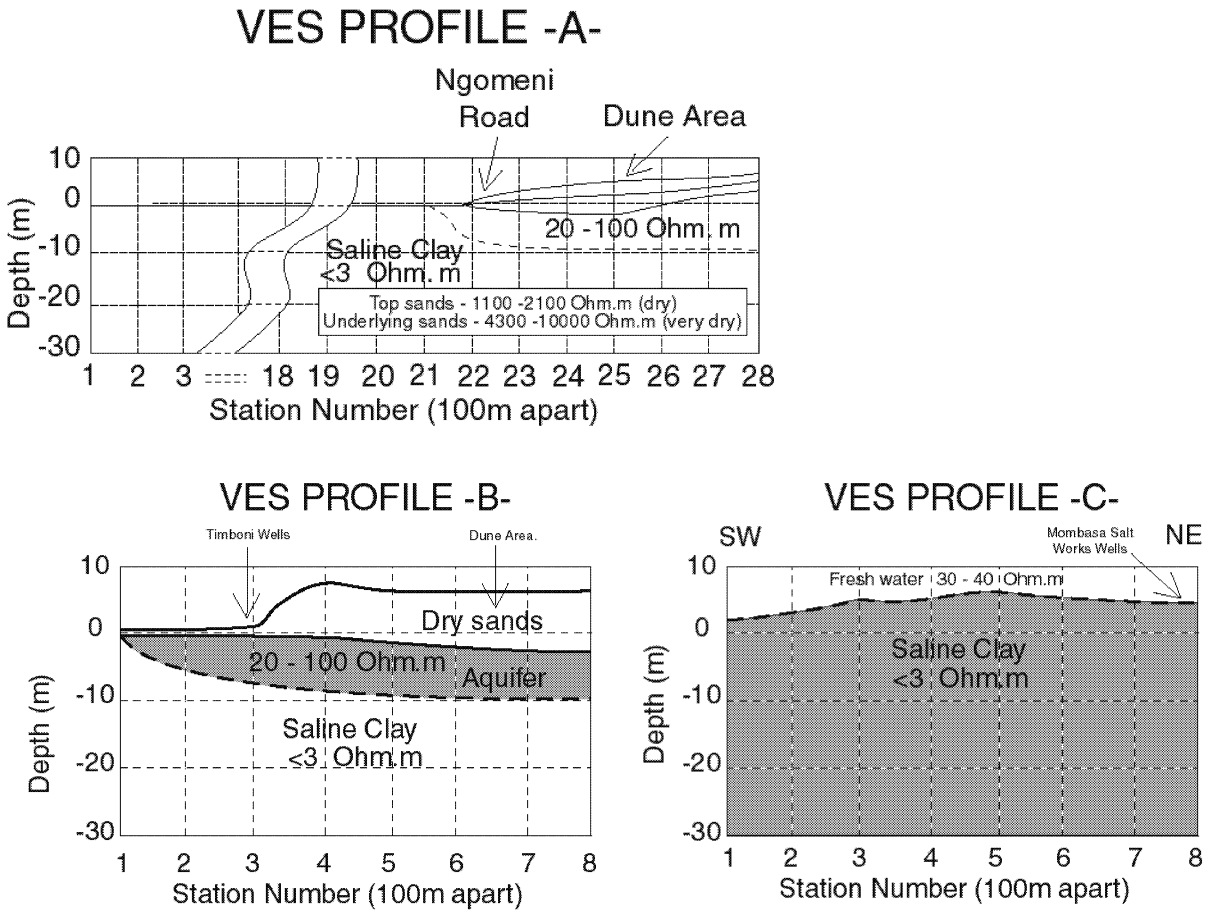

Figure 6. VES profiles.

The geophysical data suggests that there is a boundary between the freshwater and saline water at Profile C (Figure 6c), an inferred boundary between the freshwater and saline water at profiles A and B, and that the freshwater/saline water layer dips gently eastwards into the dune area. The freshwater aquifer occurs to the east of the lagoons, and is overlain by highly resistive dune sands.

Hydrogeological studies

The aquifer is generally characterised by high transmissivity (Well W002 : 447.6m^3/day; Well W018 : 266.2 m^3/day) and storativity (W002 : 0.505; W018 : 0.161). This is an indication of relatively good hydraulic properties within the aquifer and its high potential.

The piezometric surface is, in general, relatively higher at locations of higher topography, and there is a positive hydraulic gradient from the dune system to the clayey area west of Ngomeni Road. The flow directions of groundwater in the area are from the dunes to the sea in one direction and to the clays in the other direction (Figure 7). The piezometric surface is lower in the wells than in the surrounding area due to abstraction and could pose a serious threat of seawater contamination. In addition, due to the nature of the hydraulic gradient, the natural flushing of the groundwater to the sea could be hampered by over-pumping, which can lead to hydrological depressions, which form hydrologic traps from which contaminants cannot be flushed out to sea by the natural groundwater flow (Nativ and Weisbrod 1994).

Most of the wells and water holes have relatively low electrical conductivity and chloride levels (Tables 3 and 4).

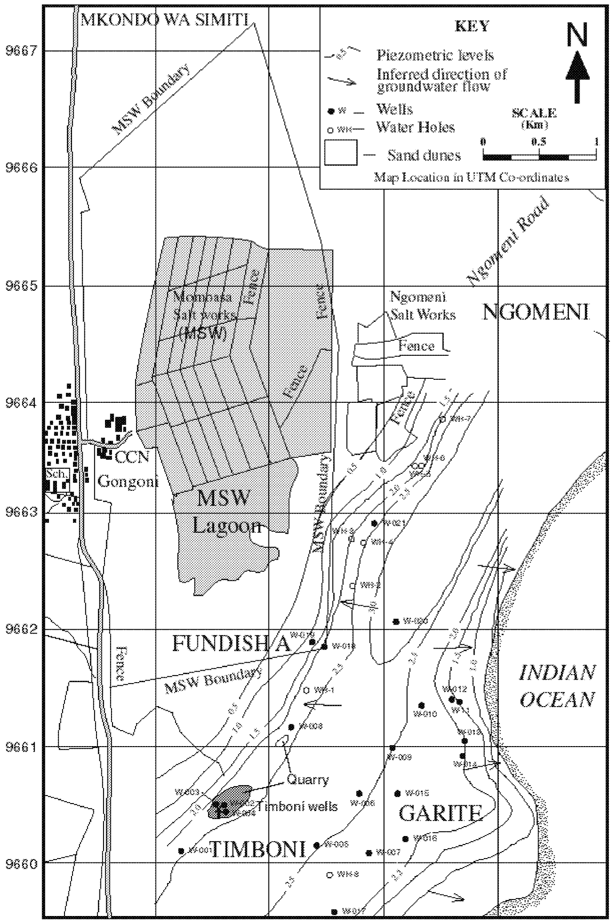

Figure 7. Flow directions of groundwater in the well area.

Table 3. Chemical analysis results for the water points.

Water Point No.	Ec mS/cm	TDS mg/l	Temp. °C	Cl mg/l	Ca mg/l	Mg mg/l	pH	Remarks
W002	473	236	29.5	<100	54	31	8	heavily used
W003	517	260	30.1	<100	78	25	8	flooded
W008	445	224	29.4	<100	25	37	8	in use
W009	610	300	29.4	<100	34	65	7	protected
W011	1060	530	28.1	100	24	77	8	in use
W012	900	450	28.1	<100	60	59	7	protected
W014	1950	980	27.2	200	19	98	8	protected
W018	930	470	31.8	100	22	126	8	heavily used
W019	7250	3640	30.4	>>500	45	72	8	abandoned
W021	720	360	30.4	<100	36	25	9	in use
WH1	400	200	31.5	<100	28	27	7	in use
WH2	540	270	30.6	<100	15	40	8	in use
WH3	2640	1320	32.5	400	49	51	9	abandoned
WH4	1740	870	32.1	200	42	92	9	in use
WH5	6430	3320	33.2	>>500	23	116	7	never in use
WH6	880	400	33.3	100	36	6	7	limited use
WH7	220	110	33.7	<100	32	7	7	in use

There is, however, a marked difference on the water points at either side of Ngomeni Road. The water points west from the road within the clayey area have relatively higher Ec and chloride values than those within the dune system to the east. These higher Ec and chloride levels could be due to infiltration of salt water from the lagoons and/or leaching of bases from the overlying clays. The chemical analyses suggest that the main factors influencing the Ec, TDS and chloride values within the dune area are the proximity to the sea and the boundary with the clayey formation.

Table 4. Chemical analyses results for the test-pits.

Test-pit Number	Ec mS/cm	TDS g/l	Temperature	Chloride	pH
TP1	76600	38300	28.6	22540	5
TP2	49200	24600	27.0	15620	6
TP3	29600	14800	27.0	20380	6
TP4	13540	6770	32.4	3770	6
TP5	23460	11730	29.4	4800	5
TP6	67550	33780	29.2	25000	5
TP7	11720	5860	28.2	-	6
TP8	39580	19790	29.8	13500	7
TP9	106080	53040	29.8	15000	6
TP10	66560	33280	29.4	23500	5
TP11	51080	25540	30.0	17650	5
TP12	52920	26460	29.0	-	6
TP13	22200	11100	29.2	4045	7
TP15	8550	4280	28.2	2300	6
TP16	33940	16690	27.6	12000	6
TP17	12300	6200	28.9	-	6
TP19	8660	4330	27.9	-	8
TP22	13160	6500	27.0	1000	7

Groundwater quality

The results of bacteriological analyses (Table 5a and 5b) reveal contamination of the groundwater resources in the area of study. The contamination is higher in public wells than in the private wells used by fewer individuals. With the exception of W018, the wells along Ngomeni Road have values in excess of 340 faecal colon counts per 100 ml. W011 in the beach area is also heavily contaminated. Relatively high groundwater contamination in water points along Ngomeni Road is largely due to the surface exposure of groundwater at the sand-harvesting quarries. Other contributing factors are settlements and high population density, poor sanitation, use of contaminated containers to obtain water, and lack of proper protection of most water points.

Table 5a. Results of the Bacteriological analysis using the membrane method.

Well No.	Faecal coliform/100ml	Total coliform count per 100ml	Protection
W002	340	780	Open well/public
W008	480	820	Open well/public
W018	10	320	Open well/public – few users
WH2	720	TNTC*	Open well/public

*TNTC = too many to count

Table 5b. Results of the bacteriological analysis using the fermentation method.

Well No.	Faecal coliform MPN/100ml	Total coliform MPN/100ml	Protection
W014	2400	2400	Makuti roof cover/public
W011	38	2400	Open well/public
W012	9	240	Makuti roof cover/private
W009	9	43	Covered with concrete slab/private

Summary and conclusions

Sand harvesting at the Timboni wellfield has exposed the aquifer to contamination from human and animal waste, and destroyed the water pumping stations. Over-abstraction is the single most significant threat to the chemical quality of water in the wells. Only one well is currently in use as the others have collapsed due to sand harvesting. The Timboni well is located where the aquifer is relatively shallow, so the threat from seawater intrusion is very high and a reduction or rearrangement of the pattern of groundwater abstraction (Freeze and Cherry 1979) should be initiated. During periods of extended drought, the threat from seawater intrusion is even higher as the groundwater level decreases. Because the aquifer is now exposed, it is subject to depletion by evaporation, and possibly, undesirable increases in salt concentration. The proposed Mombasa Salt Works (MSW) extension, on the other hand, may not adversely affect the adjacent freshwater Timboni Wellfield aquifer by percolation into the aquifer below, because of the physical and chemical characteristics of the clays and the hydraulic gradient of the freshwater system. Soil studies above the aquifer, however, suggest that lateral movement of salt water in the upper portion of the micro-fractured allophone-type clays with intercalated sands could extend for considerable distances beyond the artificial earth lagoon barriers erected by Mombasa Salt Works, and contaminate the unconfined aquifer through the clay/sand boundary. It is therefore necessary that the salt lagoon extension be kept some distance away from the freshwater/saltwater interface and water wells. For continued sustainability of the wellfields, it is necessary to stop sand harvesting in the Timboni area and to locate alternative sites further away from the freshwater aquifer. In addition, it is important that the wells are properly sited to minimise the effects of saline intrusion (Edworthy 1985). It is also necessary to rehabilitate the wellfield by covering the exposed sections of the aquifer with sand. Furthermore, the main production wells currently at the clay/sand interface should be removed from this boundary area and relocated in the middle parts of the dune system, where there is more chance of getting water of better chemical quality and free from saltwater contamination or intrusion. Due to the relatively small size of the aquifer, production should be spread over several smaller and far-spaced wells rather than rely on a large single well, to avoid over-abstraction from one point.

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4.17 Dry season sediment fluxes in the frontwater zone of the mangrove-fringed Mwache Creek, Kenya

Johnson U. Kitheka

Abstract
Mwache Creek is a typical mangrove creek along the Kenya coast. The creek receives terrigenous sediments on a seasonal basis and there is tremendous tidal influence. The supply of terrigenous sediments increases greatly during periods associated with major flood events. Most of the sediments supplied by the seasonal rivers are trapped in the upper parts of the creek with very little export to the lower frontwater zone of the creek. In the frontwater zone, sediments are imported during periods of low river discharge. This sediment import is related to the flood-tide resuspension of the bottom sediments in the frontwater zone of the creek. The resuspension of the bottom sediments is more dominant during flood tide than during ebb tide. Sediments resuspended in the main channel enter the relatively dense frontwater mangrove forest where they are trapped due to the high vegetation density and gentle slope that induce enormous friction on the water flow inside the forest.

Introduction

Much of the sediment load supplied to tidal creeks by rivers is associated with poor land-use activities at river basin level (Kitheka 1996b). The input of terrigenous sediments has both positive and negative implications. High sediment load leads to trapping of large volumes of sediments in mangrove forests, which eventually die if smothering is extensive. Sediment also increases turbidity of the water, limiting light penetration and subsequently primary and secondary production. On the positive side, input of sediments enable the mangroves to build up their environment and therefore keep in pace with sea level rise (*cf.* Ellison 1993). Studies on sediment transport provide coastal scientists and natural resources managers with information on how sediments are redistributed in mangrove wetlands and how this redistribution ultimately affects both the long- and short-term sustainability of the ecosystem. This helps in the formulation of suitable management strategies for the mangrove wetlands. However, data and information on sediment transport dynamics in mangrove creeks is not readily available (Kitheka 1996a).

Among the wide range of factors influencing sediment transport in tidal creeks, tidal range and current speed are the most important (Althausen and Kjerfve 1992; Lindsay *et al.* 1996). Channel erosion and deposition are dependent on certain critical velocities, which vary depending on the nature of tidal channel geometry and sediment supply. Given that constant resuspension by strong currents erodes the tidal channels and keeps them free of sediments, it is expected that this will prevent them from silting up even when there is enormous supply of terrigenous sediments from the rivers.

This paper examines the patterns of sediment fluxes in mangrove-fringed Mwache Creek situated along the Kenya coast. The paper also highlights the pressures in the Mwache Creek basin and how changes in the creek and the river basin may feed back on the human population.

Description of Mwache Creek

Mwache mangrove wetland occurs in the upper parts of Port-Reitz Creek (4°3′S, 39°38′E) (Figure 1). It is one of the two main tidal mangrove-fringed creeks found in Mombasa District, Kenya. The total creek area was determined from a topographic map to be 17 km^2. The mangrove forest covers an area of 12 km^2, roughly 70% of the total area of the creek. The length of Mwache Creek from the entrance to Kipevu basin is approximately 12 km.

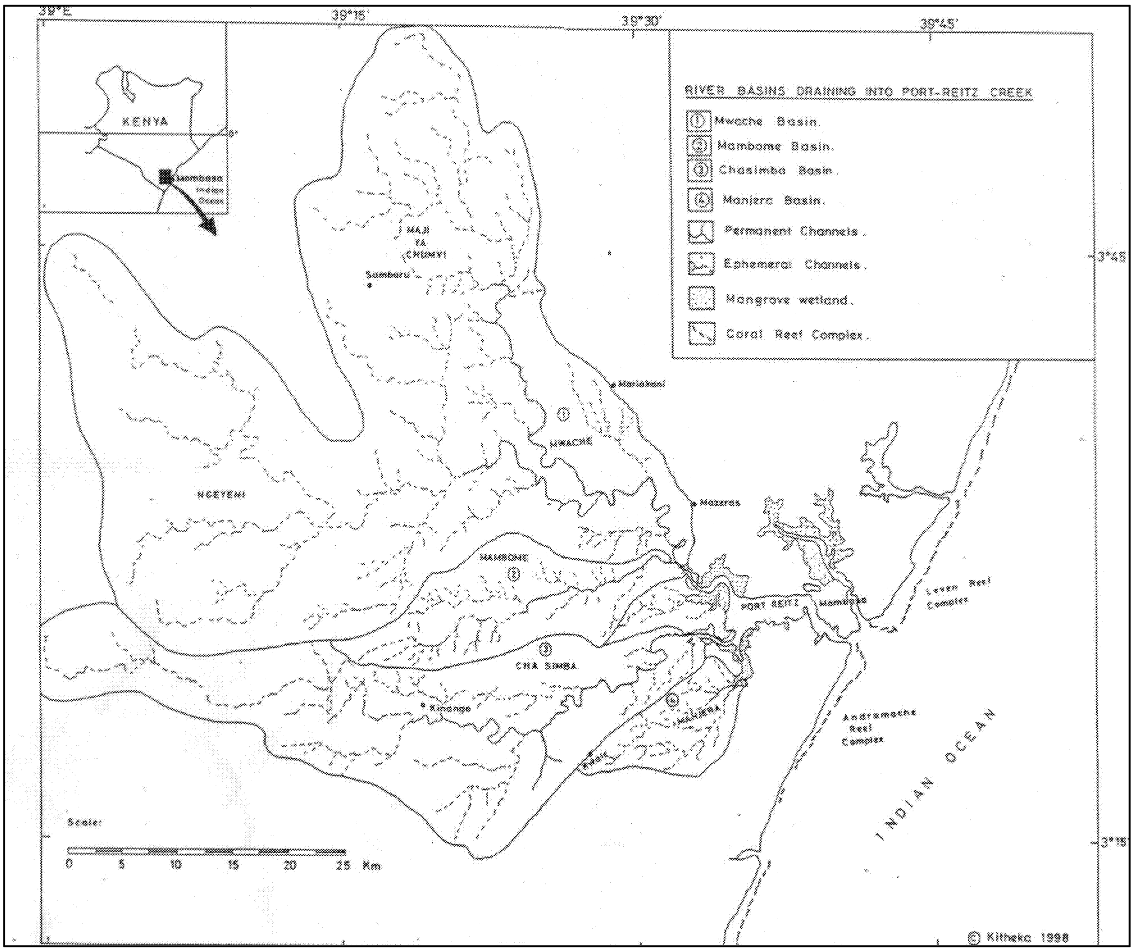

Figure 1. Mwache Creek drainage basin, Kenya.

The tidal channels are shallow, <11 m deep at the creek's entrance to Kipevu basin and less than 6 m in tidal channels fringing the mangroves. Tidal creeks meander through the wetland cutting the soft Jurassic shales and sandstone rocks which rise approximately 120 m above the creek low water level. The creek receives freshwater and terrigenous sediments from two seasonal waterways, Mwache and Mambome. Their mean discharges and basin areas are shown in Table 1. The total drainage basin area of rivers draining into Mwache Creek is 2,600 km^2. The Mwache River, with a catchment area of about 1,700 km^2, is one of the largest with freshwater discharge of the order 10 $m^3 s^{-1}$ in normal rainfall months. The dominant mangrove species are *Avicennia marina* and *Rhizophora mucronata*. The port of Mombasa, one of the largest in East Africa, is located about 4 km from the creek's entrance to Kipevu basin. Previous studies at Port Reitz Creek have been undertaken within the Mombasa port area (GOK 1975; Grosskopf and Onyango 1991), about 4 km downstream of Mwache Creek.

Table 1. The drainage basins, mean river discharges and mean sediment supply to Port Reitz Creek.

Basin	Area (km^2)	Discharge ($m^3 s^{-1}$)	Sediment supply ($kg s^{-1}$)	Sediment discharge ($t yr^{-1}$)
Mwache	1703	8.64	4.30	$4.46x10^4$
Cha-Simba	614	3.12	1.60	$1.16x10^4$
Mambome	212	1.07	0.50	$0.50x10^4$
Manjera	98	0.50	0.25	$0.26x10^4$
TOTAL				**$6.88x10^4$**

Materials and methods

Determination of sediment concentrations

Suspended sediment concentrations (SSC) were determined using gravimetric and automated methods (*cf* McGave 1979). In the gravimetric method, water-sediment mixture samples were drawn from the surface, middle and bottom water columns using a Niskin water sampler. Samples were filtered in the laboratory using pre-weighed 47 mm Whatman GF/C filters with 0.45 μm pore diameters. Salts were flushed from filtered samples using distilled water after which the samples were wrapped in aluminum foil and oven-dried at 120°C for 24 hrs. The dried filtrates were then re-weighed to determine the weight of filtered sediments, which were taken as the difference between the weight of the filter with the filtrate and the original weight of the filter. This was then related to the filtered volume of seawater to determine SSC as the amount of sediments present in a filtered volume of seawater. In the second method, an Orbital Backscatter suspended sediment sensor connected to a MicroTide pressure gauge was moored at a central location of the channel at Station 6 (see Figure 2) and used to measure SSC automatically. The instrument was programmed using a portable computer and logged in SSC at intervals of 5 minutes between January 26 and 30, 1999and also between February 2 and 23, 1999.

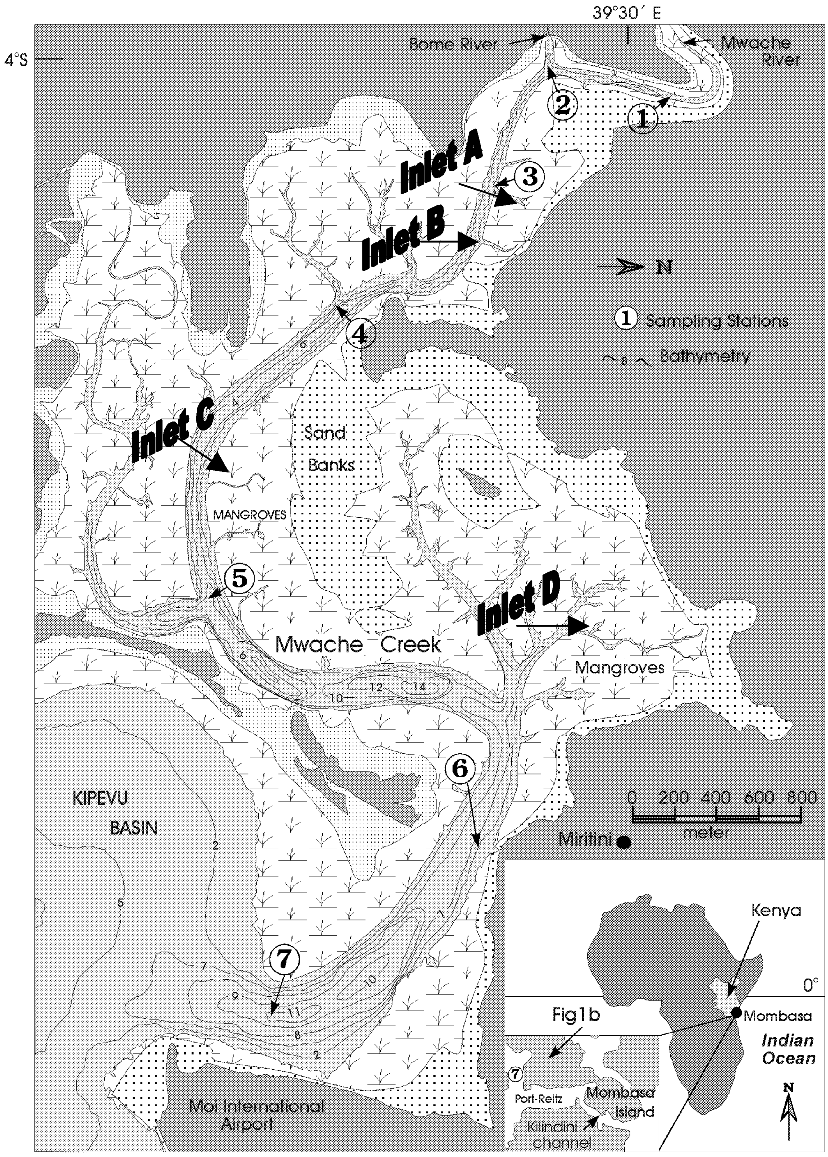

Figure 2. Map of Mwache Creek with the locations of sampling stations. For surface area and volume computations, the whole mangrove extent and tidal creeks above Station 7 were included.

Physical variables and sampling strategy

Both spot-sampling and automated continuous time-series measurements were used for salinity, temperature, tidal currents and tidal elevation. Spot surveys were carried out in the seven stations (Figure 2) using a rubber dinghy. The sampling cruise with a boat from Station 1 to Station 7 took 1-1.5 hours. Station 6 was chosen as the principal station for instrumented time-series measurements of SSC, tidal elevation and current velocities, in view of its accessibility and the availability of adequate security for the moored pressure gauges and rotor SD-6000 current meter. These instruments were moored about 1 m above the channel bed at Station 6 during the sampling periods. Water salinity and temperature were measured using an Aanderaa salinity-temperature meter. These measurements were mainly conducted in dry periods and covered both neap and spring tides. During the period of the study, river discharges were very low.

Data treatment and analysis

Sediment mass transport

The hypsometric curve of Mwache Creek was plotted from the tide-corrected bathymetric data. The surface areas (A_n) covered by specific depths (h_n) were then determined and the corresponding water volumes (V_n) computed as

$$A_n \frac{h_{n+1} + h_n}{2} = V \qquad (1)$$

Equation 1 basically refers to the volume enclosed in a specific water depth. However, since water depth changes with time (t), the tidal volume flux $Q(t)$ is computed as

$$Q(t) = A(t)\frac{dh}{dt} \qquad (2)$$

With data on corresponding instantaneous SSC C_o(t), suspended sediment flux $Q_s(t)$ was then computed as

$$Qs(t) = Q(t)\, C_o(t) \qquad (3)$$

The tidal volume flux $Q(t)$ is also computed using current velocity U and surface area A_s as

$$Q(t) = UA_s \qquad (4)$$

This method assumes uniform velocity distribution across the channel. Similar approaches have been applied in salt marsh tidal creeks and estuaries (Lindsay *et al* (1996).

Erosion and deposition of sediments

The time series data on SSC and current velocities measured in the period February 15 - 23, 1999 were used to derive empirical constants in the sediment transport relation. The standard vertically averaged sediment mass conservation equation applied in a finite section of the channel (about 100 m) is simplified as follows:

$$\frac{\partial (HC)}{\partial t} = M_e - M_d \qquad (5)$$

where H is the water depth, C is the depth-averaged SSC and t is the time. The source and sink terms are erosion (M_e) and deposition (M_d) respectively. These terms are governed by specific critical velocities, which were determined by examination of the simultaneous plots of SSC and current velocities. The sediment deposition rate (M_d) was computed as:

$$M_d = \begin{cases} CW_S\left(1-\frac{U}{U_d}\right)^2 ; U<U_d \\ 0 ; U>U_d \end{cases} \qquad (6)$$

where U is the current velocity outside boundary layer, U_d is the critical velocity for settling and W_s is the sediment settling rate (0.0005 m/s). The critical deposition stress τ_d, is computed as:

$$\tau_d = \rho C_d U_d^2 \qquad (7)$$

and the erosion of sediments from the channel bottom (M_e) was calculated as:

$$M_e = \alpha \left(\frac{U}{U_e} \right)^2 - 1 \qquad (8)$$

The above equation is applicable if the current velocity is higher than the critical erosion velocity ($U>U_e$). U_e is the critical velocity for erosion and α is an empirical constant that can be derived from equation 7.

Results

Tidal characteristics and current velocities

Tides measured at the frontwater zone of the creek are purely semi-diurnal with two low and two high waters occurring approximately every 25 hours. The neap and spring tidal ranges are 1.3 m and 3.1 m respectively. The dominant low frequency signal approximates 12.3 hrs, which is typical of modulation caused by tidal forcing. The maximum flood and ebb tidal current velocities at Station 6 during spring tide are 1.25 m/s and 1.38 m/s respectively and at neap, the maximum ebb and flood tide current velocities are 0.55 m/s and 0.52 m/s respectively.

The spring high tide water volume at Mwache Creek is approximately 60×10^6 m^3 while the spring low water volume is 17×10^6 m^3 when the depth change due to a 3 m tidal range is taken into consideration. This yields a tidal prism of about 43×10^6 m^3 which is equivalent to the frontwater zone tidal volume exchange of roughly 70 % per tidal cycle in spring tide. The average tidal volume flux is estimated to be 2,300 $m^3\ s^{-1}$. Since there is no significant sink or source of freshwater, the mean frontwater zone tidal volume fluxes of 2,233 $m^3\ s^{-1}$ and 937 $m^3\ s^{-1}$ could be considered as representative tidal flows during spring and neap tides respectively. These data are within acceptable limits given the assumptions that sea level spatial variations upstream of Station 7 are not significantly different.

Zonal SSC variations and gradients

Large seasonal and neap-spring SSC variations were noted for the inner mangrove stations. The SSC variations during the period of this study could not be attributed to changes in river discharge since drought prevailed in 1998-1999 and there was no significant supply of sediments from the river basins. The seasonal river discharges were often less than 0.05 $m^3\ s^{-1}$ and SSC in riverwater was less than 0.04 $g\ l^{-1}$. This means the river sediment supply into the creek was less than 0.002 $kg\ s^{-1}$ which is much lower than the long-term average of 7 $kg\ s^{-1}$.

Even with this rather low river discharge, the highest SSC was found mainly in the backwater mangrove zone where SSC reached 0.50 $g\ l^{-1}$. This zone had also relatively high dry season salinities ranging 36-38 psu. In the frontwater zone, SSC was less than 0.09 $g\ l^{-1}$ and salinities were 2-3 psu lower than those measured in the backwater zone. The prevalence of high SSC in the backwater zone and relatively low SSC in the frontwater zone implies a general decrease towards the open Indian Ocean, and trapping of sediments in the inner zones of the creek. The backwater zone also showed a relatively large SSC standard deviation of 0.30 $g\ l^{-1}$.

Resuspension of bottom sediments in main tidal channel

There was evidence of flood-tide resuspension of bottom sediments in the frontwater zone during the dry seasons. Rapid increase in SSC occurred during flood tide followed by a rapid decline during high waters and also during ebb tide. This is possibly because most of the suspended sediments are trapped in the mangrove forest, so that only a small quantity is available for transport seaward during ebb tide. Periods of bottom sediment re-suspension were associated with maximum current velocities of the order of 1.0 m s^{-1}. Significant erosion occurred for flood-tide current velocities above 0.30 m s^{-1}. There were also spring-neap variations in the magnitude of suspended sediment concentrations. The maximum SSC occurred during spring tide and there was a reduction in SSC level during neap tide. Maximum resuspension of the bottom sediments in the frontwater zone also occurred in spring tide because strong velocities are usually experienced in spring. Since the magnitude of tidal current velocities decline substantially during neap tide, the magnitude of resuspension is also reduced by about 50% in the frontwater zone during neap tide.

The computation of erosion and deposition rates in the frontwater zone (using equations 6 and 8) showed that rates of erosion reach $10x10^{-4}$ kg m^{-2} s^{-1} and those of deposition reach $5.0x10^{-4}$ kg m^{-2} s^{-1}. Thus sediment production through erosion of the bottom sediments is of the order of $5x10^{-4}$ kg m^{-2} s^{-1}. The higher rate of main channel bottom erosion compared to deposition points to the fact that the main tidal channel in the frontwater zone does not silt up. This explains why the channel remains free of sediments even after a period of major sediment inflow into the creek.

Suspended sediment fluxes

The suspended sediment fluxes, computed using equation 3, were higher in spring tide (1200 kg s^{-1}) and lower in neap tide (400 kg s^{-1}). The mean spring ebb tide sediment flux is 690 kg s^{-1} and the mean flood tide sediment flux is 1740 kg s^{-1}. In neap tide, mean ebb tide sediment flux is 340 kg s^{-1} while that in flood tide is 460 kg s^{-1} (Table 2). The difference between neap flood-/ebb-tide sediment fluxes is +121 kg s^{-1}, while that in spring is +1057 kg s^{-1}. There is thus spring neap-tide sediment flux difference of about 30%. These high spring sediment fluxes are probably due to high spring tidal volume fluxes, which are 3 times higher than those experienced during neap tide (Table 2). During the period of this study, the flood tide sediment fluxes in both spring and neap tide were much greater than the ebb tide. There was therefore a net sediment import of the order 80,000 tonnes into the creek. The imported sediment was probably sediment that was discharged into the creek by the Mwache River during the 1997 *El Nino* event. Sediment flux patterns are illustrated in Figure 3.

Table 2. The mean spring -neap tidal current velocities, tidal volume fluxes and mean sediment fluxes at station 6 in the period February 2-23, 1999.

	Spring tide	**Neap tide**
Mean flood tidal volume flux (m^3 s^{-1})	2179	914
Mean ebb tidal volume flux (m^3 s^{-1})	2286	959
Mean flood velocity (m s^{-1})	1.25	0.52
Mean ebb velocity (m s^{-1})	1.31	0.55
Mean flood sediment flux (kg s^{-1})	1740	460
Mean ebb sediment flux (kg s^{-1})	690	340

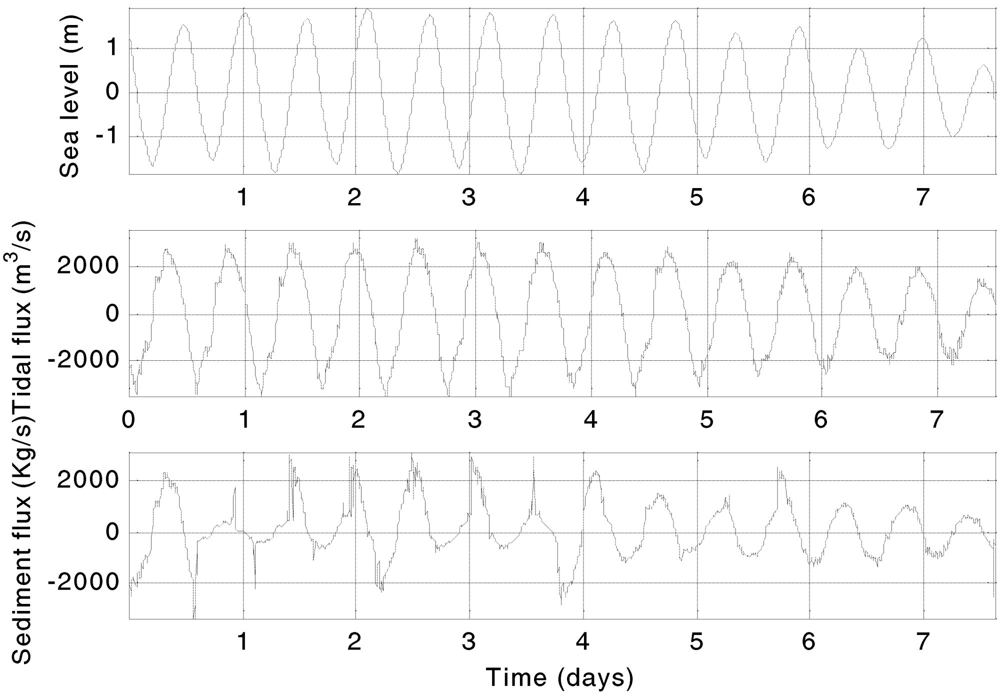

Figure 3. The key patterns of sediment fluxes in the frontwater zone of Mwache Creek during a period of relatively low river discharge.

Trapping of sediments in the frontwater zone mangrove forests

The patterns of sediment flux in the Mwache Creek frontwater zone mangrove forest in spring tide was determined along 450 m transects running from the bank of the main tidal creek to the upper tidal limit of the forest. The mean SSC within the mangrove forest was 0.054 g l^{-1} (±0.02 g l^{-1}, N=15). The maximum mangrove forest SSC was 0.096 g l^{-1}. The mean flood-tide sedimentation rate calculated using the relation $W_s.C$ was 0.027 g m^{-2} s^{-1} (±0.01 g m^{-2} s^{-1}, N=15) with the maximum sedimentation rate of 0.48 g/m^2/s. The SSC mode in the mangrove forest was 0.05 g l^{-1} which with the typical sediment particle settling velocity (W_s) of 0.0005 m/s yield flood tide sedimentation rate of 250 g m^{-2} per tide per spring tidal cycle. However, if the mean SSC is used, the mean flood tide sedimentation per tidal cycle increases slightly to 270 g m^{-2} per tide which is still within the same order of magnitude as that computed using the mode SSC. It must be noted that this approach provides only an estimate of sediment flux during flood tide and does not provide an estimate of the ebb-tide sediment flux. The net sedimentation in the mangrove forest is therefore much lower than the flood-tide sedimentation since it is the difference between flood-tide and ebb-tide sediment fluxes. In fact, the magnitude of ebb-tide sediment flux is slightly lower (of the order 260 g m^{-2} per tide) than that of flood tide, which means the net sediment flux into the mangroves is of the order 10 g m^{-2} per tide. These results show that there is trapping of sediments in the frontwater mangrove forest. Trapping occurs because of dense mangrove forest cover as well as gentle slope, which induce friction on the tidal flow, resulting into very low current velocities less than 0.10 m s^{-1} (see also Wolanski and Ridd 1986; Furukawa and Wolanski 1996; Furukawa *et al.* 1997). However, the magnitude of the net sediment flux into the mangrove forest is a function of the tidal range and bottom sediment resuspension in the main channel.

Importance of river supply of sediments

This study was implemented in relatively dry period. Both short and long rains were below average in the coastal region of Kenya. There was therefore no significant generation of river runoff in the Mwache River basin as the river discharges were less than 0.05 m^3 s^{-1} in most period of the study. The river SSC was also very low, often less than 0.04 g l^{-1}. This means that the river sediment supply into the creek was less than

0.002 kg s^{-1}, which is much lower than the long-term average of 7 kg s^{-1}. However in the period between October and November 1997, heavy rainfall associated with the *El Nino* event caused a tremendous increase in river discharge of both freshwater and terrigenous sediments. During this period, it was estimated that the river discharge was 500 m^3/s and river SSC was of the order 0.5 g l^{-1}, so sediment discharge was of the order 500 kg s^{-1}. The sediment supply into the creek over the two months period of high flow was estimated to be $1.3x10^6$ tonnes. This estimate was later confirmed by determination (using sediment cores) of the volume and depth of the deposited terrigenous sediments within the backwater zone mangrove forest. In normal rainfall years, seasonal rivers draining into Mwache Creek usually flow for about 120 days and supply an equivalent of $5x10^4$ tonnes of sediments, which is less than 4% of that discharged into the creek during the 1997 *El-Nino* event. A survey conducted to determine the spatial distribution of deposited terrigenous sediments and SSC showed that most of the sediments discharged into the creek are trapped in the backwater zone of the creek, particularly in the zone above Station 4. Most of the trapping of silt and fine sand occurred on the backwater zone mangrove forest and clay particles were trapped within the main channel above Station 4. The frontwater zone mangrove forest was surprisingly not affected in any significant way from the enormous input of terrigenous sediments into the creek.

Human pressures

Human pressures in the Mwache basin may be classified into two major categories: (1) anthropogenic pressures at the Mwache Creek coastal-marine system level and (2) pressures at Mwache River basin level. The anthropogenic pressures are mainly felt more seriously in the mangrove forest wetland. There is evidence that the cutting down of mangrove trees beyond sustainable level is reducing their sediment trapping capability. There is also evidence that the area under mangrove cover in the creek is reducing. This reduction has increased in recent years due to an increase in demand for building material and fuelwood in the Mombasa Municipality.

Within the Mwache River basin, poor land-use activities associated with shifting cultivation, livestock grazing and deforestation have lead to an increase in the rates of soil erosion (Kitheka 1996b). Substantial quantities of terrigenous sediments therefore reach the creek during rainy seasons. The implication for the sustainability of both marine ecological systems and human cultural features are enormous, particularly in periods of high rainfall events such as those associated with *El-Nino* conditions. The enormous supply of sediments increases turbidity in the creek and thus affects light penetration into the deep layers of the water column. This in turn affects primary production and fisheries, on which the large population within the basin depends for their livelihood and daily sustenance. As a result of heavy sediment supply during the 1997 floods, mangrove roots were smothered and this led to death of nearly 10% of the mangroves in the upper zone of the creek. This is already affecting the inhabitants due to reduced fish catches, since mangroves act as nursery grounds and habitats for fishes and crustaceans of commercial importance. Further reduction of mangrove hectarage in the creek may in future lead to a drastic reduction in catches of these organisms. Another major effect is the siltation of the potential harbor sites at Kipevu. Unless remedial measures are taken to conserve the mangrove forest and manage land use in the Mwache basin, it will be necessary to incur high expenditure on maintenance dredging of the Port of Mombasa.

Conclusions

Sediment load into Mwache Creek from the seasonal rivers in normal rainfall years is low so that most of the terrigenous sediments are trapped in the upper parts of the creek. During such periods, there is very little export to the lower frontwater zone of the creek. Most of the sediments supplied by the Mwache River do not reach the Indian Ocean. In fact there is import of sediments in the frontwater zone of the creek during periods of low river discharge in dry season. This import of sediments is due to the flood-tide resuspension of the bottom sediments in the frontwater zone of the creek. Resuspension of the bottom sediments is more dominant in flood tide than in ebb tide. The sediments resuspended in the main channel enter the relatively dense frontwater mangrove forest where they are trapped due to the dense mangrove vegetation and gentle slope, which induces enormous friction on the flow inside the forest. This study has dwelled more on the sediment transport dynamics in the frontwater zone. Conditions in the degraded backwater zone may differ from those in the frontwater zone, where the mangrove vegetation is less dense and the rate of tidal flushing in the backwater zone above Station 4 is low. More studies, focussing on the relationship between sediment fluxes and tidal dynamics, will be implemented for both frontwater and backwater zones of the creek. Future studies will also aim at determining the patterns of sediment fluxes in the tidal inlets that link the mangrove forest with the main tidal channel. Such studies should target both the degraded and non-degraded zones of the creek.

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4.18 The Tana River Basin and the opportunity for research on the land-ocean interaction in the Tana Delta

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Introduction

The Tana River basin is one of the five main drainage basins in the Republic of Kenya. In terms of river discharge, it is one of the largest and also one of the most important drainage basins. It occupies about 23% of the total land area and contributes 32% of the total river runoff in Kenya. The basin is composed of the vast eastern plateau forelands, which sprawl between the Central Kenya Highlands to the west and the coastal strip on the east. The river flows down a gentle slope towards the Indian Ocean. The government of Kenya has initiated a number of significant water resources development projects in the basin. These include agricultural projects, particularly large-scale irrigation and hydroelectric power development schemes. As the river drains into the Indian Ocean, it passes through a mangrove-fringed estuary at Kipini. Apart from discharge of freshwater and terrigenous sediments into the Indian Ocean, the river also supplies a large quantity of dissolved and particulate nutrients, which makes Ungwana Bay and the Tana Delta one of the most productive fishery grounds in Kenya. Most previous studies have focussed on the Upper Tana Basin and very few studies have been implemented for the Lower Tana Basin and the Tana Delta. This paper examines the hydrological and geographical characteristics of the basin and discusses the need for studies on land-ocean interaction at the Delta.

Hydrology and climatic conditions

The Tana River Basin has a spatial extent of approximately 132,000 km^2 which is equivalent to about 23% of the total area of the Republic of Kenya (Table 1) (Ojany and Ogendo 1985). The main catchment area of the river is Mount Kenya (5199 m) and the Aberdare Ranges in the Central Highlands of Kenya. The snow-covered peaks of Mount Kenya provide continuous replenishment of the river, making it one of the few perennial river systems in East Africa. However, despite the high rainfall in elevations greater than 1800 m, the Tana River displays marked seasonal variations in river flow. As a result of rainfall pattern, the river usually has two distinct periods of high flow of three months total duration, separated by dry seasons when the flow frequently drops to one-fifth of the long-term average.

The total length of the river is about 1,102 km, from the Central Kenya Highlands to the Indian Ocean. The river takes a north-easterly course as it flows from the Kenya Highlands and then plunges over the Gtaru Falls (134 m) into the semi-arid landscape that constitutes the middle course. It forms a wide arch, then veers south and opens into a wide valley where it meanders through a floodplain into the Lower Tana Basin. The most important tributaries in the Kenya Highlands include the Sagana, Chania, Thika, Saba Saba, Maragua, Ruamuthambi and Mathioya rivers. In the Lower semi-arid zones, the river receives contributions in the rainy season from several ephemeral tributaries such as Tiva, Hiriman, and Kokani.

The Upper Tana catchment area in Central Kenya covers an area of 7,950 km^2 (Schneider 2000) which is about 6% of the total basin area, but it contributes more than 70% of the river runoff. The Upper Tana Basin has been the focus of a number of studies geared toward understanding soil erosion and sediment transport dynamics (Dunne and Ongwenyi 1976; Ongwenyi 1983; Schneider 2000).

Table 1. The main drainage areas in Kenya.

Drainage basin	Area (km^2)	% of the total area of Kenya
Lake Victoria	49,000	8.4
Rift Valley	127,000	21.8
Athi River	70,000	12.0
Tana River	132,000	22.7
Ewaso Ngiro	205,000	35.1

Rainfall in the Upper Tana Basin is controlled by the Indian Ocean monsoons in combination with pronounced orographic effects of the inland hills and mountains (Ewbank and Partners 1974). The Aberdare and Mount Kenya regions receive heavy rainfall (>1800 mm/year). Between 1800 and 1200 m ASL, rainfall is high, 1000-1800 mm yr^{-1}. However, in the Lower semi-arid regions, rainfall is much Lower ranging 500-750 mm yr^{-1}. This is particularly so in semi-arid zones of the basin such as Embu, Kitui, Mwingi and Tana River districts. Evaporation in these areas is about 1800 mm yr^{-1}, but there are significant seasonal variations.

The basin in general experiences two rainfall seasons controlled by the south-east (between March and September) and north-east (between October and early March) monsoons (Ojany and Ogendo 1985). The southe-east monsoon is associated with the long rains, which occur between March and June, with maximum rainfall in May. The north-east monsoon is associated with the short rains (November and December) with peak rainfall in November. However there are often great inter-annual variations in rainfall, partly due to *El -Nino* and *La Nina* southern oscillation cycles.

Rainfall in the Upper Tana Basin is more important than snow melting on Mt. Kenya in increasing the river runoff, with a good relationship between rainfall in the Central Kenya Highlands and river runoff in the basin. The maximum river discharge at Garsen in the Lower Tana Basin is experienced in June and December, implying a time lag of about one month between peak rainfall and peak river discharge in the Lower Tana Basin. The river discharge varies from less than 10 $m^3 s^{-1}$ in the dry seasons to over 2,000 $m^3 s^{-1}$ during flood flow conditions (UNEP, 1998). During normal rainfall years, river discharge ranging 100-500 $m^3 s^{-1}$ is common in the Lower Tana Basin. The mean annual river runoff has been estimated to be 4,700x10^6 m^3 per year, or about 32% of the total mean river runoff in Kenya estimated to be 14,836 x10^6 m^3 per year (Ojany and Ogendo 1985). Due to rainfall anomalies in the Western Indian Ocean which result in exceptionally high rainfall in Central Kenya, the Lower Tana Basin experienced extreme floods in 1937, 1947, 1951, 1957-8 and 1961 (Ojany and Ogendo 1985). However the severity of these floods has been reduced since the construction of Masinga high dam in the Upper Tana Basin (Otieno and Maingi 2000).

Land use and water resources programmes

The Upper Tana catchment area in Central Kenya covers an area of 7,950 km^2 (Schneider 2000) which is about 6% of the total basin area. ample rainfall and good volcanic soils have favoured maximum exploitation of the agricultural potential of the highlands and heavy human population settlement (Ojany and Ogendo 1986), predominantly encompassing the Central Kenya administrative districts of Kirinyaga, Murang'a, Nyeri, Thika, Meru and Embu. The main urban centers include Thika (also an important industrial center), Murang'a, Embu and Meru.

The soils of Central Kenya are well-covered with dense evergreen forests. There are mainly deeply weathered loams with high infiltration rates and low erodibility despite the steepness of the land (Ewbank and Partners 1974). Between 1800 and 1200 m ASL, rainfall is high (1000-1800 mm per year) and slopes are steep with loamy soils. However, where the former woodland vegetation has been removed and replaced with cultivated agricultural crops such as tea and coffee, bananas, vegetables, maize and beans, continuous tillage has reduced the natural fertility of the soil and this has necessitated the use of industrial fertilizers to boost crop production. Most of the crops grown in the region do not provide adequate ground cover, so the rate of erosion is greatly accelerated despite the generally low erodability of the soils

(Otieno and Maingi 2000). Major sediment-contributing areas are the densely populated and intensively cultivated foothills of the Aberdares, rather than the semi-arid lowlands (Schneider 2000). In the Murang'a and Nyeri districts the steep, intensively cultivated slopes are the main contributors of sediment into the Masinga Dam and the Tana River (Dunne 1974).

The main hydroelectric power-(HEP) generating dams constructed across the Tana River are in the Upper Tana Basin. These include Masinga, Kamburu, Gtaru and Kiambere HEP dams. Masinga Dam, the Uppermost reservoir, has impounded 45 km of the 1,102 km long Tana River and created a body of water covering 25 km^2, one of the largest artificial lakes in East Africa. Masinga Dam acts as a high dam, controlling water storage and discharge for the turbines of the dams downstream (Kamburu, Gtaru and Kiambere). Data showing the contribution of the main Tana River tributaries to the total sediment discharge into Masinga Dam is shown in Table 2. In addition to these reservoirs, Sasumua reservoir provides much of the water used in the Kenya's capital city, Nairobi.

Table 2. Mean annual discharge and sediment inflow into Masinga reservoir.

Tributary	Water Discharge (m^3)	Suspended sediment inflow (t yr^{-1})	Bedload discharge (t yr^{-1})
Tana	2239	3,890.000	390,000
Maragua	412	2,290,000	230,000
Saba Saba	120	990,000	100,000
Chania	205	870,000	90,000
Thika	252	420,000	40,000
Total	**3228**	**8,460,000**	**850,000**

Source: Otieno and Maingi (2000).

Poor land-use practices in the rich agricultural Upper Tana basin have increased soil erosion and a large quantity of sediments enters the reservoirs annually (Dunne and Ongwenyi 1976; Ongwenyi 1983). The long-term sustainability of these dams is in doubt due to reduction of their design capacities from heavy siltation (Schneider 2000; Otieno and Maingi 2000). The Tana River sediment load is 1-7 million t yr^{-1} during high-flow conditions (Schneider 2000). However, the mean annual discharge of water-suspended sediment into Masinga reservoir is 8.46 million tonnes against a mean annual water discharge of 3,228x10^6 m^3 (Otieno and Maingi 2000). This means that the sediment discharge downstream of the Masinga Dam is slightly less than 8 million tonnes per year, because the reservoirs trap a large portion of sediments from the Upper Tana Basin which is the main source of sediments carried by the river.

Various studies have yielded different sediment load estimates (Table 3). This is due to differences in the accuracy of the river runoff data, varying periods of data analysis and differences in techniques applied in the computation of sediment fluxes. Quantitative sediment yield estimates are difficult to produce with any degree of certainty. Prediction of the future rates of sediment yield is even more problematic given the variation in the annual discharge of the river. Most of the previous studies have extensively relied on the use of historical river discharge and suspended sediment concentration records to determine the sediment yield in the Upper Tana catchment (Schneider 2000). River and sediment discharge records include large gaps in some of the data and inaccurate analytical and river-gauging approaches result in erroneous estimates. There is a need to improve on the river and sediment discharge monitoring through regular maintenance of river gauging stations and regular collection of suspended sediment concentration data at representative river gauging stations.

Table 3. Sediment yield for the Upper Tana River basin.

Source of data	Sediment yield (t yr^{-1})
Gibb (1959)	280,000
ILACO (1971)	250,000
Dunne (1975)	1,283,000
Dunne and Ongwenyi (1976)	568,547
Edwards (1979)	334,730

the Lower Tana Basin is mainly semi-arid with rainfall of 500-750 mm yr^{-1}. Low rainfall, hot climatic conditions (30-35^{o}C) and poor soils have resulted in low agricultural potential and therefore low human population densities. The human population is concentrated along the floodplains of the river, particularly in Tana River district, where the annual influx of floodwater during rainy seasons deposits fertile silt on the floodplains which in turn sustains the cultivation of rice and bananas by the riverine tribal communities. In the more arid zones of the basin, the main land-use activity is livestock grazing.

The Lower Tana Basin also has relatively flat coastal plains, which have encouraged the development of large-scale irrigation schemes such as the Bura, Hola and Tana Delta schemes. These development ventures were initiated by the Kenya government with generous bilateral and multilateral financial assistance from donor countries. However, these schemes have proved uneconomical and have failed. The main crops grown in these irrigation schemes were cotton and rice. As a result of the low nutrient status of soils in the Lower Tana Basin, there was heavy application of industrial fertilizers to improve production. At present, the only surviving large-scale irrigation project is Mwea-Tebere Irrigation and Settlement scheme in the Upper Tana Basin.

The Tana Delta dynamics

Despite being the largest deltaic system in Kenya, the Tana River delta and its associated estuaries has not been targeted for comprehensive research studies. Thus the hydrological and ecological dynamics within the delta are poorly known. The processes within the delta can be discussed only on the basis of very limited field investigations and reconnaissance surveys that have been carried out in the area.

The Tana River in its lower reaches forms a complicated drainage pattern of braided channels and meanders, with ox-bow lakes formed as a result of the interlocking erosion-deposition events. Downstream of Garsen, the river starts to break up into several distributaries which combine to form what is loosely referred to as the Tana Delta. In fact these distributaries are thought to be former channels of the river that have since been abandoned when the river shifted its course as it headed towards the Indian Ocean. The Tana River has changed its course over different time-scales (Ojany and Ogendo 1985), but the reasons for doing so are poorly known. The present main course of the river is to the north of the delta, where it enters into the Indian Ocean through a mangrove-fringed estuary at Kipini. Its former outlet is about 32 km south-west of Kipini.

The flow of nutrient-rich freshwater to the Indian Ocean has led to the formation of a rich fishery at Ungwana Bay, which is regularly targeted by large-scale commercial fishing companies because of the abundance of prawns (UNEP 1998).

The tidal influx from the Indian Ocean penetrates approximately 2-7 km into the estuary at Kipini, taking saline water into the inner portions of the delta. As evidence of the outflow of river water into the Indian Ocean, there is no coral reef complex in Ungwana Bay. Within the bay, circulation is driven by the river discharge, tides, monsoon winds and the coastal current systems, particularly the seasonally reversing Somali Current and the East African Coastal Current. Unfortunately, there are no studies detailing the degree of influence of these forcing factors on water circulation in the bay and delta. There have also been no hydrological studies geared at examining the main circulation patterns in the delta, including also the patterns of material (nutrient and sediment) transport and exchange. This is unfortunate since the Tana

Delta is one of the most important riverine systems in Kenya and is regarded as an important wetland for wildlife conservation by the Ramsar convention, of which Kenya is a signatory. Lack of studies in the area seem to have mainly been due to insecurity and inaccessibility. The delta is located in a remote part of the Coast Province with a poor transport network and facilities. Encroachment by armed bandits has also compromised security and development in the area.

The Tana Delta is certainly different from the Mwache, Mida and Gazi creeks (Kitheka 1998; Kitheka *et al.* 1999; Kitheka 2000), but there are certain fundamental aspects that could be similar given that these systems are fringed with mangroves and all receives freshwater discharge. Mangrove wetlands have been known to modify water and sediment circulation patterns and their presence along the estuary is certain to alter sediment transport dynamics.

Anthropogenic impacts and synergies

In the absence of any reliable data on anthropogenic impacts in the Tana Delta, it is difficult to offer a concrete synthesis of the likely relationship between man and the biophysical system at the delta. However, experience in similar systems helps us to understand the possible connections between the two (Kitheka 1998; Kitheka *et al.* 1999; Kitheka 2000).

There is no doubt that soil erosion in the Central Kenya highlands is impacting negatively on hydroelectric power reservoirs in the Upper Tana Basin (Ongwenyi 1979; Ongwenyi 1983; Schneider 2000; Otieno and Maingi 2000). The design capacities of these dams declinedover the years with the result that the Masinga reservoir cannot hold enough water for the generation of electricity. The reservoir also cannot hold enough water in periods of high river discharges and therefore its role in flood mitigation is being reduced steadily. In periods of severe droughts, there is rationing of electricity throughout the country, which severely constrains the industrial sector since industrial production in Kenya is highly depended on power supplied from the Tana River HEP dams.

Reduction in the design capacities of the Upper Tana River reservoirs has also complicated water supply schemes in both rural and urban areas due to heavy expenditure required for water treatment particularly in the removal of silt. This has increased the cost of treating water for domestic and industrial uses. Low storage capacities of the reservoirs has also reduced the volume of water available for rural and urban water supply, large and small-scale irrigation schemes.

In irrigation schemes located in the Lower Tana Basin, siltation of irrigation channels has necessitated expensive irrigation canal maintenance works, and irrigation water pumps constantly break down as a result of clogging due to high silt content of the river water.

In the Tana Delta, the main impact of heavy siltation has been the destruction of large hectarage of mangrove forests, which are important coastal ecosystems. Mangroves are thought to be nursery grounds of fishes and crustaceans of high commercial value, so their destruction affects the fisheries sector. This will definitely impact negatively on the socio-economic status of the local population. However, apart from destruction due to high sediment supply, destruction of mangroves also occurs through extensive uncontrolled cutting by local inhabitants. The destruction of the mangrove wetlands through these processes reduces the sediment-trapping role of the mangroves, allowing more terrigenous sediment to enter directly into the Indian Ocean where the resulting highly turbid water may be detrimental to marine ecosystems.

Research needs in the Tana Delta in the context of LOICZ

A comprehensive hydrological study should be initiated under the auspices of the Land-Ocean Interaction in the Coastal Zone (LOICZ) project, to examine the main circulation and material transport (both sediments and nutrients) patterns in the delta, and the influence of the mangrove forests in trapping terrigenous sediments from Tana River with a view of advising on their management. The project should also aim at determining the dynamics of sediment and nutrient transport along the Ungwana Bay coast, taking into account the patterns of the south-east and north-east monsoons as well as the dynamics of the coastal current systems. The project should run for two to four years, targeting both high and low river flow conditions, with time-series measurements of tides, tidal flow, tidal current velocities and directions, river discharge, suspended sediment concentrations, salinity, temperature and nutrient concentrations particularly silicates, nitrite-nitrogen, nitrate-nitrogen and orthophosphates. These parameters should be measured with reliable and accurate scientific equipment, including Orbital Backscatter turbidity sensors, MicroTide pressure gauges, Aanderaa Recording current meters (RCM-9), Atomic Absorption Spectrometer (AAS) and Auto-Analyser. Some of this equipment is currently available at the Kenya Marine and Fisheries Research Institute (KMFRI) at Mombasa. KMFRI is a government of Kenya research organisation with the mandate of conducting all aspects of aquatic research in Kenya.

Conclusions

Although the Tana River is one of the largest and most important river system in Kenya, its linkage with the Indian Ocean is at present poorly known. There have never been comprehensive studies on the hydrology of the Tana Delta. Variations in material concentrations and fluxes to the Indian Ocean are only poorly known. Most studies have been concentrated in the Upper Tana Basin but, because delivery ratios of different materials transported by the river have not been established, it would be scientifically inappropriate to use Upper Tana data to compute water and material fluxes to the Indian Ocean. The Tana River Basin, including the Tana Delta, offers a good location for determining how changes in the coastal system may feed back on the human system. It is recommended as perhaps the best case study site in Africa for studying Land Ocean Interactions in the Coastal Zone.

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4. 19 Determining patterns of contaminant flux through basins and the coastal zone over time: methodologies and applications for Africa

John G Rees, John Ridgway and T Martin Williams

Abstract

Integrated coastal zone management is increasingly focused on links between catchments and coasts in which the coastal zone is seen as part of a continuum between the river basin and the open sea. To enable effective environmental management decisions to be made there is a need for a good appreciation of which human activities and natural processes are the most important controls on the flux of key materials, such as C, N, P, sediments and contaminants through this continuum. To achieve this it is necessary to link spatial and temporal patterns of both human activities and natural change within river basins and along coasts with the flux of key materials to the sea. This is done best using sedimentary records and two UK research programmes, the Land-Ocean Interaction Study and the Land-Ocean Contamination Study have developed simple, cost-effective, methodologies that may be applied readily to the flux of contaminants (principally heavy metals) from land sources to the sea. The methodologies use pre-existing geochemical datasets, where available, and are based on comparison of the characteristic natural geochemical variability in river basins and on coasts with the geochemical record contained in sediment cores from contaminated sites in fluvial or nearshore settings. Examples are described, including cases from Kenya and Zimbabwe, and the potential for their adaption to calculating the flux of other key materials, mainly sediments, is discussed. The benefits of applying the methodologies to other parts of Africa, largely using pre-existing data, and a typological approach to scaling-up conclusions as utilized by LOICZ are set out.

5. CASE STUDIES

5.1 The National Water Act of South Africa: implications for estuaries and the coastal zone

Janine Adams, Susan Taljaard and Barbara Weston

From resource development to resource management

The principal objective of South Africa's National Water Act (Act 36 of 1998) is to balance long-term protection of water resources with short- and medium-term use. The Act recognizes that water is part of a larger ecosystem that provides us with services and benefits such as drinking water, water for economic development, transportation and recreation opportunities. The Act has signaled a shift from resource development to resource management and the environment. The environment is no longer seen as a competitive use of water, but rather the base from which the resource is obtained, and must therefore be protected.

Progress and development with regard to Resource Directed Measures for estuaries, the implementation process and links with other water resources, comprise a collaborative effort involving a number of estuarine scientists and managers.

The Reserve

The National Water Act (Act 36 of 1998) makes provision for a Reserve to be determined prior to authorization of water use (examples of the 11 water uses include agriculture, industrial uses, waste discharges). The Reserve is the *quantity and quality* of water required to satisfy basic human needs, considering both present and future needs and to protect aquatic ecosystems in order to secure biological sustainable development and use of the resource.

The importance of freshwater to estuaries – case studies

Over the last eight years a number of studies funded by the Department of Water Affairs and Forestry have determined the freshwater requirements of estuaries:

- The **Olifants** is a permanently open estuary on the dry west coast. It has the largest supratidal saltmarsh area in the country and is dependent on floods to keep the habitat moist and flush out accumulated salts. Further freshwater abstraction from this estuary will result in saline intrusion in summer and agricultural return flow stimulates algal blooms and reed growth.
- The **Great Brak** is a temporarily closed estuary on the southern Cape coast. Releases of water are made from the Wolwedans dam to keep the mouth of this estuary open, particularly at those times of the year when fish and invertebrate recruitment takes place from the sea.into the estuary. If the mouth remains closed and water levels increase then the intertidal saltmarsh plants and animals will die.
- The **Tugela (Thukela)** on the east coast functions as a river mouth, as the brackish, mixing zone occurs out at sea. This system provides sediment and nutrient rich water to the marine environment. This is important as it results in beach nourishment and maintains the productive prawn industry on the Tugela banks.

From these and other case studies we have a generic understanding of the freshwater requirements of estuaries. **Baseflow** is important as it keeps the mouth of an estuary open. The flow required to do this varies due to local coastal conditions e.g., beach slope, wave action, availability of sediments. Baseflow is also important as it maintains a longitudinal salinity gradient required for biotic diversity.
Freshwater pulses (freshettes) introduce nutrients into an estuary and stimulate water column productivity. **Floods** flush out accumulated sediment and thus affect the long term sediment erosion / deposition processes.

Development of methods for determining the reserve

To facilitate the determination of the ecological reserve for aquatic ecosystems, water resources have been sub-divided into groundwater, rivers, wetlands and estuaries. Methodologies to determine the ecological reserve are still being developed and tested for each of these resources. There are currently three levels of Resource Directed Measure determination (RDM) for estuaries:

1. Rapid determination of RDM which is a desktop assessment.
2. Intermediate determination (which takes approximately two months to complete)
3. Comprehensive determination (which takes approximately 12 months to complete).

The level of RDM determination required depends on the sensitivity of the water resource, the scale and degree of the impact of proposed water uses, and the urgency for a reserve determination. All three levels include six basic steps that are used to determine the reserve for estuaries:

Step 1. Delineate the geographical boundaries of the estuary.
Step 2. Determine the eco-regional type.
Step 3: Assess present state and determine reference condition.
Step 4: Determine present ecological status and ecological importance.
Step 5. Determine and set the Ecological Management Class (EMC)
Step 6. Quantify the reserve and set the Resource Quality Objectives (RQO)
Step 7. Design appropriate resource monitoring programme.

The intermediate reserve process can be demonstrated using the Palmiet and Nahoon estuaries.

State of the Environment indicators

Components of the Reserve project such as the assessment of **present ecological status** and **monitoring requirements** links up well with another project on the development of State of the Environment indicators for estuaries. This project falls under the umbrella of the **SA-ISIS** project (South African Integrated Spatial Information Systems). SA-ISIS is essentially a 'switchbox' to access remotely located information and databases. One would be able to log onto a website and reach a comprehensive estuary database containing information on ecological health, conservation importance and sensitivity to development. The web-site will also house a set of fourteen generic 'State of the Environment" indicators to enable managers to select those important for tracking the health of their particular estuary. Management information will focus on what equipment is needed for monitoring, how, where and when to sample, and how to analyse, interpret and present the outcome of the monitoring. Ecological implications of indicator trends will be highlighted and there will be direct lines of access to specialist advice.

5.2 The dynamic interaction of Maputo Bay and its river catchments: a proposed model catchment-to-coast integrative project for the AfriBasins initiative

Pedro M.S. Monteiro, Pete A. Ashton, Rheta Stassen and Dirk Roux

This project is aligned with southern African initiatives to increase collaboration and co-operation in decision-making on shared river basins of SADC. This collaborative project seeks to maximize opportunities for integration between different disciplines and regional aquatic resource management institutions, and increase internal and external capacity to address and resolve resource management problems between shared river basins and the coastal systems that depend on them.

This project is primarily developing the skills and the tools, which can be used to support present and future needs of sustainable management of Maputo Bay and its key catchments. The objective is not to formulate the management strategies *per se* as that is the responsibility of the actual resource managers but to provide the basis (understanding and tools) on which quality decisions can be made. This approach can then be extended and applied in other systems where the management of the coastal zone requires an explicit understanding of land forcing through the dynamics of river catchments.

Background

After more than two decades of near paralysis, the economic development of Mozambique is now underway with an intensity which could lead to unexpected social and environmental impacts. This applies particularly to the metropolitan area of the capital city of Maputo and its surrounding environment, which includes the Maputo Bay and its associated rivers and estuaries, which together comprise the Maputo Bay System. Maputo has historically been the seaport for the Witwatersrand (Gauteng) and Highveld industrial and mining heartland of South Africa as well as an important tourism destination. Following a period of political change (1975-1995) the country in general but Maputo specifically is undergoing rapid re-development through both industrialization and tourism development. One of the main consequences of such rapid development is that in many instances there is no holistic way of assessing the impacts of investment decisions and in the main EIA are carried out on case-by-case basis. This mostly excludes an overall assessment of the ecological or health implications of cumulative or interactive perturbations.

The environmental and economic management of the impacts of human activities in the Maputo Bay system has two important scales:

- **Local Scale**: this comprises activities, uses and needs in the immediate vicinity of the system.
- **Regional Scale**: this comprises the activities, uses and needs in the catchment areas of the 5 rivers that flow into the Maputo Bay system.

The socio-economic importance of the Maputo Bay system as a nucleus of growth both in Mozambique and for the Maputo Corridor IDZ makes it imperative that future beneficial uses are not foreclosed and that the environmental and human health impact risks of growth are constrained.

This study aims to provide both the understanding and the tools to allow these impacts and their costs to be explicitly determined in order that investments take a more regional and strategic perspective.

The system and its main characteristics

The Maputo Bay system comprises a complex system of linked water bodies, which include five rivers (Incomati, Maputo, Tembe, Umbeluzi and Matola) discharging into three estuarine systems (Espirito Santo, Maputo and Incomati) which open into Maputo Bay. The bay system, in turn, is linked to the southern end of the Mozambique current through the gyral feature of the Maputo Bight. The main concerns and likely forcing factors are summarized in Table 1. Important natural and anthropogenic features, which could have an economic bearing on the sustainable growth of the system are:

- **Rivers from South Africa**: the five rivers discharging into Maputo Bay all originate from the South African or Swaziland catchment areas and act as vectors to transfer catchment management problems in water quality to the bay itself. Recent studies of sediment biogeochemistry in the Maputo Bay system have shown that the natural erosion of mineral rich rocks and mining waste discharges from the catchment areas dominate its characteristics. While this is a recognized trans-boundary problem there has been little quantitative assessment of the impact of such forcing. There is an independent study of some aspects of the Incomati River catchment part of the system and a key part of the proposal development will be to link up and coordinate the two efforts.

- **Sediments dynamics**: Maputo Bay is a soft edge system – it has sandy beaches, silt-rich mangroves and substantial sediment loads from the river inputs. These have major implications: costly maintenance dredging of a shipping channel, coastal erosion and stability of sensitive ecosystems such as coral reefs and mangroves. The impacts of river catchment management are felt within the bay itself. The extent to which catchment erosion linked to rural development strategies contribute to the costs of annual dredging in the Maputo Bay system is not understood.

- **Ecology**: The Maputo Bay system not only includes an important coral reef system (Inhaca Island reef) but also extensive mangroves (~10,000ha.) which are a key habitat for the local prawn and clam industry as well as both pelagic and reef fisheries. These vulnerable systems are not only under threat from population pressures but also from water quality and sediment (turbidity) forcing. While their key role in the long-term stability of the local economy is not clearly understood or quantified it is likely that ecological and resources exploitation will continue.

- **Effluent discharges**: the Maputo area contains both old and new industrial facilities and a large and dense urban area whose sewage is only partly treated. These have had a significant impact on the local economy through the banning of filter-feeder collection, eutrophication and sediment contamination. While these impacts are at the moment limited to the waters around the urban - industrial zone further environmental deterioration can be envisaged if the hydrodynamic/water quality and ecological interactions are not correctly understood.

- **Islands**: the islands in the vicinity of Maputo Bay are both centres of bio-diversity and popular tourism destinations. These sensitive sub-tropical systems are vulnerable to environmental change driven by remote decisions such as river catchment management and local water quality through the discharge of domestic and industrial effluents.

These factors make this an ideal system where predictive modelling and DSS expertise and IT based technology can serve to strengthen regional aquatic management institutions, improve communication, improve the quality of information for investment risk management and for sustainable growth of the local and regional economies. Such an approach will empower local and regional system managers with tools and understanding, which will allow them to weigh up the consequences of certain decisions and interact with investment bodies constructively and proactively.

Goal:
To design, develop and validate a generic catchment-to-coast planning and management support system for the southern African region, which can also be implemented beyond the region. This will enable water resource managers to incorporate trans-boundary water resource issues and strategies in their medium- and long-term development plans. Recent advances and developments in water resource management policies are based on a new set of philosophies; this has opened the way for the development and implementation of new technologies and new operational procedures that are designed to support and promote sustainable water resource management on a whole catchment basis, including the coastal zone.

Objectives:
To achieve this goal, the following objectives can be set for this project:

1. Technical

- To develop a sound scientific understanding of the dynamic linkages between catchments and coastal processes, and the ways in which these linkages are influenced by activities within a catchment; and
- To develop appropriate tools and the predictive capability to quantify and internalize the linkages between these processes and the implications of catchment management decisions and actions on water quantity and quality. In this process, it is important to be able to distinguish between, and make provision for, the influences of natural and anthropogenic activities.

2. Institutional

- To develop a clearer understanding of the social, ecological and economic factors which contribute to, or control, the sustainability of water resources;
- To develop and expand effective institutional and organizational links that will enable efficient sharing of knowledge, tools, insights, experience and responsibilities for water resources and catchment management;
- To promote and develop effective capacity creation (including scientific and management skills) amongst potential participants and beneficiaries;
- To effectively and efficiently co-ordinate and integrate inputs from different disciplines (social, economic, political, ecological) into a truly trans-disciplinary programme; and
- To re-position the southern African expertise base for provision of technical and management advice to support regional water management policies, including impacts on coastal systems.

3. Resource management

- To promote and ensure the development of a sound scientific and socially acceptable basis for decision-making by resource managers, that will enable a regional perspective to be taken;
- To ensure that the potential benefits of successful catchment management are also extended to those whose socio-economic well-being is governed by the sustainability of coastal systems dependent on upstream catchments; and
- To provide local solutions in the context of regional-scale impacts.

Rationale

- Lack of information leads to the inability to make proper decisions that, in turn, leads to poor policy implementation and failure to deliver benefits to stakeholders on the ground;
- This is a trans-disciplinary study which seeks to bridge the gaps between scientific (especially ecological) understanding, and the social and economic interests of stakeholders;
- The need to shift the focus of water resource management from a predominantly “reactive” mode, to a more “proactive” mode, with a regional (whole catchment) focus; and
- There is a growing need to develop regional-scale solutions that seek to resolve resource management issues, and also seek to establish “local” problem-solving capacity and appropriate institutional and organizational structures to facilitate stakeholder participation and involvement.

Table 1. Matrix reflecting the relationship between issues and impacts for Maputo Bay.

Environmental Issue	Impacted systems	Impacted beneficial uses	Driving process	Forcing scale	Management responsibility
Coastal Erosion	Beaches Islands Coral reefs	Urban infrastructure Tourism	Catchment flow and sediment transport dynamics Wave (wind and ocean) energy Sand transport within the bay Dredging of shipping channel Sea level Land use	Local Regional (river catchments)	Maputo and Matola councils CFM Emodraga
Disposal of dredged material	Shipping channel Beaches Islands Estuaries Mangroves Coral reefs Sediment biota Water column biota	Fishing Mariculture Harbour and shipping Saltworks	Circulation Flocculation Catchment processes Contamination	Local Regional (river catchments)	CFM Emodraga Fisheries Institute (IIP) Environment Affairs
Water and sediment quality	Estuaries Mangroves Coral reefs Sediment biota Water column biota	Fishing Mariculture Harbour and shipping Saltworks Industrial activity	Local effluents Catchment effluents Flocculation Catchment erosion Dredging Flooding Land use	Local Regional (river catchments)	Water Affairs City councils Environment Affairs
Biodiversity	Estuaries Mangroves Coral Reefs Sediment Biota Water Column Biota	Fishing Mariculture Tourism Recreation	Water quality Sediment quality Sediment (mud and sand) dynamics	Local Regional (river catchments)	

5.3 Development of ecological indicators for the North Sea

Saa H. Kabuta

This paper describes the development of ecological indicators as management tools, and the steps taken in the Netherlands for the proper management of the Dutch section of the North Sea (NCP).

Background information

Because of the increase in intensity of human activities and the increased attention for the conservation of species and habitats in the North Sea, discussions over the health of the North Sea ecosystem started at the third North Sea Ministers Conference in 1990. This was followed by a number of workshops under the auspices of the North Sea Task Force and the Oslo and Paris Conventions (OSPAR). Regulations of the European Union, treaties for the conservation of the Rhine, Meuse and Scheldt and the International Maritime Organisation (IMO) were further factors that influenced management procedures for the ecological quality of the North Sea.

In the Netherlands, the Ministry of Transport, Public works and Water Management (V&W) and the Ministry of Agriculture, Nature and Fisheries Management (LNV) set up and are implementing various projects that will create better understanding of the ecosystem of the Netherlands section of the North Sea (NCP). The results from these projects should enable the formulation of policies that could lead to the creation of a balance between the effects of human activities and the preservation of the natural qualities of the North Sea ecosystem. This balance is expected to lead into an effective management of both the ecosystem and the various uses of the North Sea.

One of the projects undertaken in the Netherlands is the GONZ project (GONZ is Dutch acronym for indicator development for the North Sea), designed to develop ecological indicators for the NCP. These indicators are based on various monitoring data which when properly used could evaluate the effects of human impacts on the ecosystem, thereby making it possible for the policy makers and the managers of the NCP to evaluate the effects of their policy and management recommendations on the quality of the ecosystem (Kabuta and Duijts 1999).

This paper presents the steps taken towards the development of ecological indicators for the NCP and the role they could play in describing the level of human impacts on the various attributes of the ecosystem. The relationships between the changes in the ecosystem and the policy recommendations for the North Sea are considered by using examples of the ecological indicators developed in the GONZ project.

The study area

The North Sea is part of the North Atlantic Ocean. It is surrounded by the coasts of Great Britain, Norway, Denmark, West Germany, the Netherlands, Belgium and France (Figure 1) and has a total area of 575000 km^2 which is 14 times the size of the Netherlands. The North Sea is a relatively shallow part of the Atlantic Ocean, only 40 m deep in the southern part, but from averaging 100-200 m in the north and, especially off southern Norway, down to 700 m.

The North Sea is one of the most productive seas in the world. The rivers deposit enormous amounts of nutrients (nitrate and phosphate) into the sea while the water flow from the south of the North Sea thoroughly mixes these nutrients.

In addition to the nutrient deposits from the rivers, solar radiation in the North Sea supports high primary production levels (<50 - >1000 gC m^{-2} yr^{-1}). The cumulative effect of these factors has resulted in a high level of production which has led to numerous commercial activities in the North Sea, including fisheries.

The North Sea is one of the busiest seas in the world, with huge numbers of ships including freighters, trawlers, tankers, gravel and sand excavation ships (Kabuta and Duijts 1999). There are also a large number of platforms for oil and gas mining industries from the surrounding countries.

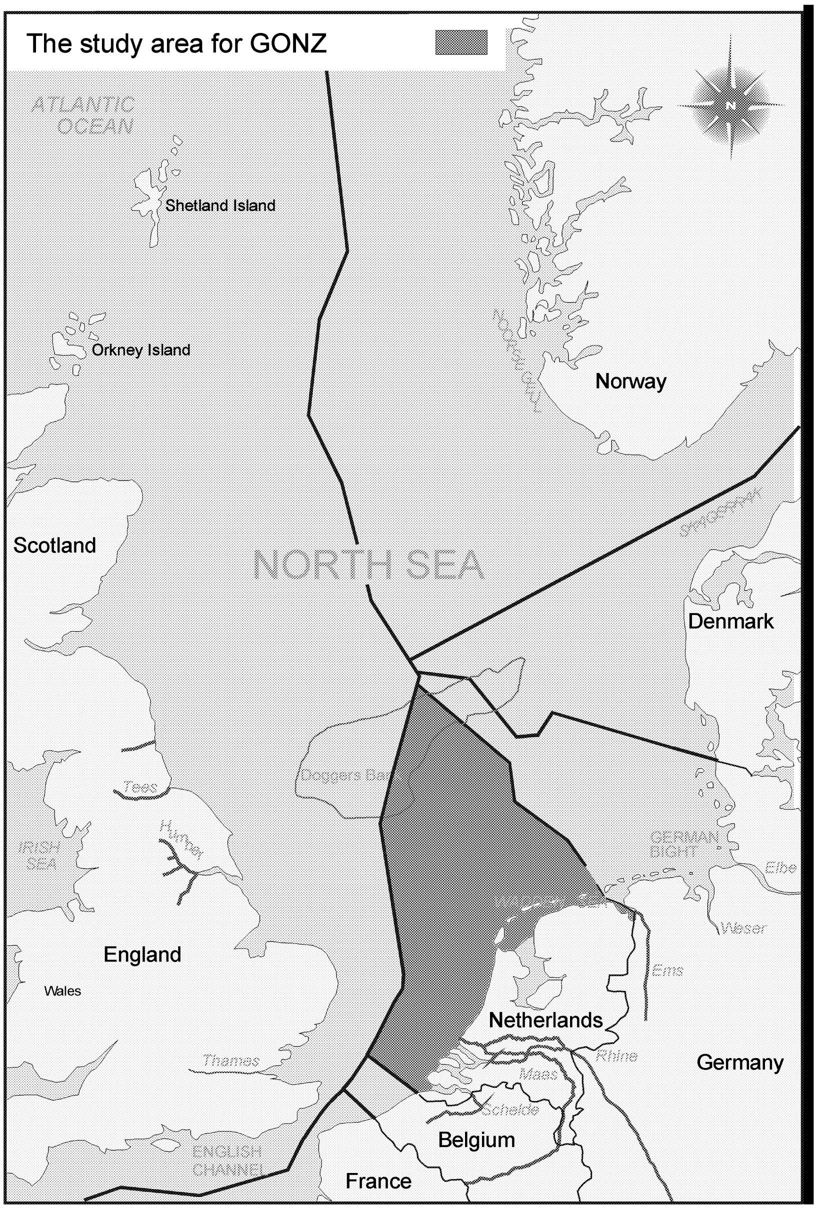

Figure 1. The North Sea and the Netherlands Continental Plate (NCP).

Why Ecological Indicators for the Netherlands?

The increase in commercial activities in the North Sea and increased awareness of the degradation of the marine ecosystem led to the need for a reliable, effective, reproducible and multifunctional management tool for the North Sea ecosystem. The construction of such an integral management tool in the Netherlands was initiated by the North Sea Directorate of the Ministry of V&W., with support from the Ministry of LNV.

The Ministry (LNV) makes policies for the conservation of nature in the North Sea whilst the Ministry (V&W) has the task of making policies that will result in sustainable use of the North Sea. These two ministries have a common view of the development of ecological indicators for the North Sea (Duel *et al.* 1997). The new tool will be based on the principles underlying the existing tools but will replace those tools, which were designed for similar purposes by the two ministries. These tools include the 'general methods for describing and evaluating ecosystems (AMOEBE)' and the 'use nature conservation parameters (NDT)'. The AMOEBE was developed for the Ministry V&W whilst the NDT was developed for the Ministry LNV.

Various tools for the evaluation and assessment of the water and nature policies were in use. For the water policy the ecological evaluation system AMOEBE (Ten Brink and Hosper 1989; Ministry of Transport, Public Works and Water Management 1989) was used. As the interest in maintaining a high quality of ecosystems in the Netherlands increased, the quest for developing and using a more integrated instrument for the monitoring and evaluation of the related policy recommendations increased. The two main operational instruments (AMOEBE and NDT) were considered outdated and could not be used to answer the numerous policy-related questions over the quality and management of the ecosystem. To address all the policy issues, a new set of tools was therefore needed. These tools must be relevant not only to the ecology of the water system and the related policy recommendations for water and nature conservation but also to the policy recommendations for the environment (Latour *et al.* 1993).

The GONZ project

The GONZ project was started in 1996 and has been implemented by the National Institute for Coastal and Marine Management in the Netherlands (RIKZ) under contract from the North Sea Directorate (DNZ) of the Ministry of V&W. Both organisations (RIKZ and DNZ) are departments under the ministry of V&W and are involved in the management, monitoring and evaluation of the Netherlands section of the North Sea. The RIKZ takes part in the preparation of new policies for the North Sea and shares the responsibility of analysing the effects and the viability of existing policy measures for the North Sea ecosystem. The DNZ is responsible for the management of the North Sea and issues licenses for commercial activities in the North Sea.

The GONZ project is designed to develop ecological indicators for an integral evaluation of the policy recommendations for the North Sea and should functions as an eye opener for the development of robust policy evaluation instruments for the description of the ecological qualities of both marine and fresh waters in the Netherlands.

Participating Institutions

The development of ecological indicators (GONZ) is a multidisciplinary research project being carried out by several research institutions in the Netherlands which study the North Sea to increase knowledge about the ecosystem and to provide advice for policy- and decision-makers in the various sectors. Among these institutions are the National Institute of Coastal and Marine Management (RIKZ), the Royal Netherlands Institute for Fisheries Research (RIVO), the Netherlands Institute for Sea Research (NIOZ), The Green World Research Institute (ALTERRA), the National University of Groningen (RUG), the Institute of Environmental Sciences, Energy Research and Process Innovation (TNO) and the Institute for Inland Water Management and Wastewater treatment (RIZA) .

The expected qualities of the GONZ indicators

The indicators developed from the GONZ project must be able to assess the water management (V&W) and nature conservation (LNV) policies for the North Sea. At the same time the use of a common set of indicators must provide solutions to the various (scientific) criticisms against the existing evaluation systems (AMOEBE and NDT). To enhance the development of the indicator systematic it is accepted that these existing evaluation tools must form the basis. The indicators must include both biotic and abiotic parameters, to measure biodiversity, ecological functioning and sustainability of the North Sea. The indicators could be process variables, species, species groups or indices expressed in ecological terms. Variables related to the ecosystem could also be used as indicators.

Steps taken towards the development of the Indicators

Based on the terms of reference above, development of the indicators involve a number of specific targets. Essential requirements were:-

1. the design must comply with the project objectives for GONZ;
2. the design must have an obvious relationship to the (mutual) water and nature policy objectives;
3. the design must provide solutions to criticism of the existing tools (AMOEBE and NDT) as well as integrating them as much as possible.

1. The design must comply with the GONZ project objectives
The main objectives for the development of the indicators are as follows:

- to develop an evaluation system for the ecological quality of all water systems in the Netherlands.
- to be able to assess and evaluate both the water policy and nature policy for the North Sea.
- to provide a solution to the various (scientific) criticisms of the existing evaluation systems (AMOEBE and NDT).
- the evaluation system is also required to integrate the existing evaluation systems.

Even though the GONZ project is focused on the development of indicators for water and nature policies for the North Sea, some of the indicators are linked to specific environmental policy themes. The ecological quality of the North Sea is influenced by activities along the rivers, especially those that result in higher concentrations of nutrients and micro-contamination in the North Sea. Therefore indicators which are related to the productivity of the North Sea ecosystem contain information regarding the issue of eutrophication (caused by excess nutrient input). Indicators which are developed to describe the effects of various human activities in the North Sea do also contain information regarding environmental policy themes, e.g., TBT distribution by the shipping industry.

2. The design must have an obvious relationship with the water and nature policy objectives.
The development of the indicators was preceded by a condensed analysis of the related national policies (Water and Nature) and the existing evaluation tools (AMOEBE and NDT). The most important elements from the existing tools were the parameters which could be used for the quantification of the indicators. The advantage of using these parameters is that they are already known to both the policy makers and the managers of the ecosystems and could be recognisable by them when presented as key parameters for the indicators.

2a. The Water policy for the North Sea
The Ministry of Transport, Public Works and Water Management (V&W) bears the responsibility for the development and implementation of the water policy for the national waters in the Netherlands. In order to carry out the GONZ project, an analysis of the national water policy objectives was carried out. This was done by studying the third and fourth policy documents for water.

In the Third Memorandum on Water Management policy - NW3 (Ministry of Transport, Public Works and Water Management 1989) - recommendations were made for the sustainable management and utilisation of the water systems. These policy recommendations are the result of a strategy which is based on the concept of integral water management. The basic principle behind this strategy is that the objective of the water policy could be achieved through an integrated approach to the problems of the water systems. These policy recommendations were further specified in the Fourth Memorandum on Water Management (Ministry of Transport, Public Works and Water Management 1997). The Fourth Memorandum also recommended the integration of policies (also from other departments) for water, town and country planning, environment and nature. This policy recommendation created the opportunity for a more area-orientated approach: a combination of an integrated generic approach for the national collective objectives and a more specific regional approach, taking into account the local conditions and opportunities.

The objective of the Fourth Memorandum on Water Management policy is as follows:
"*Having and maintaining a safe country and the development and conservation of healthy and resilient water systems which guarantee sustainable utilisation.*"

Thus, the water policy for the North Sea is geared towards sustainable development and use of the water system. Fishery and ecological objectives are brought into balance using an integrated approach in relation to the ecosystem qualities. The precautionary and ecosystem approaches are used for this purpose. Coastal expansion plans go hand in hand with investments in the coastal environment. These views were used as targets for realisation in the subsequent years (Ministry of Transport, Public Works and Water Management 1997).

2b. The nature policy
The Ministry of Agriculture, Nature Management and Fisheries (LNV) is responsible for developing policies that will improve the quality of nature in the Netherlands (including the related water systems). This ministry is also responsible for making policy recommendations regarding fisheries in the North Sea. Recommendations for the nature policy in the Netherlands are laid down in the Nature Policy Plan (Ministry of Agriculture, Nature Management and Fisheries 1990). The main objective of the nature conservation policy is defined as:
"sustainable maintenance, recovery and development of natural and landscape values."

This objectives could be expressed in two words: biodiversity and naturalness.

The most important means for the fulfilment of these objectives is the realisation of the National Ecological Network (Ecologisch Hoofd Structuur - EHS). Species protection-related measures are also taken, such as the shelter of grassland birds and geese outside the EHS. Key points are:

- the EHS is a connected network of ecosystems which are nationally and internationally considered important and are to be durably maintained.
- the EHS must be realised in 2018 and comprise 700,000 ha land and 7,000,000 ha of water (Ministry of Agriculture, Nature Management and Fisheries 1995).
- all large marine and fresh waters, including the total NCP, are key areas within the EHS.

3. The design must provide solutions to the criticism of the existing tools (AMOEBE and NDT).

Problematic issues around the use of the existing evaluation tools
The AMOEBE and NDT approaches use limited numbers of species for evaluation of the water systems. The problem with this is the uncertainty over the drawing up of a one-to-one relationship with regards to making trend analyses of the said species. In the Water policy the biodiversity objectives are evaluated based on a set of species which describe a cross-section of the ecosystem. The occurrence of the species in this set can be controlled to a significant level by managers. This set comprises both common and rare species. The first group can be used to follow the process of change in the ecosystem as a consequence of the policy recommendation, while the second group (rare species) can be used to assess the deviation from the desired situation. The so-called ITZ species (I=species to be conserved from international point of view, T=species that are declining in number, Z=species that are uncommon in the Netherlands) are used for the evaluation of the biodiversity objectives for the nature policy for terrestrial ecosystems. This approach was only effective to a limited extent for the aquatic ecosystems including the North Sea.

The extent of controllability of the ITZ species through policy measures is ambiguous. In practice evaluating biodiversity objectives using the ITZ species are restricted. The observation of changes in the biodiversity can be based upon ITZ species through monitoring. However, rare species can hardly be observed in monitoring programmes. This results in a significant interference, which in turn masks the signal.

Apart from these criticisms, the AMOEBE and the NDT concepts provide opportunities for an integrated evaluation system. The underlying similarities between the two concepts are seen from their attempts to define the ecosystem. The aspects to be defined in the two systems differ but these can be integrated. Integration opportunities lie mainly in enhancing and broadening the scopes of the two evaluation systems. Enhancement can be achieved through the inclusion of natural processes and structural characteristics of the ecosystem other than just species. Broadening can be achieved using another choice and definition of the ecosystem and the related species. The indicators and indicator parameters should then give a general picture of the ecosystems. To develop such a robust indicator systematic, a conceptual framework preceded by a set of criteria is necessary.

Perception of the design
The state of and the changes in the ecological quality of the North Sea can only be understood properly with the use of indicators which are related to the relevant and characteristic processes and patterns (structural characteristics) of the North Sea ecosystem. Therefore the characteristics of the North Sea

ecosystem are pivotal to the development of the evaluation system. The indicators must be linked to one of the various ecosystem characteristics. The relationship between indicators and the mutual water and nature policy themes is specified in the evaluation system using the ecosystem characteristics. The quality of the indicator is determined using one or more parameters. Two groups of indicators can be identified:-

- **system indicators:** these indicators enable observation and quantification of developments in the ecological qualities of the water systems ;
- **utilisation indicators:** these indicators enable analysis and quantification of impacts of use on the ecological quality of the water systems.

By definition the indicators for human activities should be controllable by the use of policy recommendations. The system indicators cannot be controlled by the management forces. The steps taken towards identification of the indicators are shown in the schema below (Figure 2).

1. Water and Nature Policy objectives

2. Biodiversity | Ecological functioning of the North Sea with (sustainable) use

3. Characteristics of the ecosystem

Species (groups) Ecotypes Populations	Productivity Feeding structure (types) Hydro-, morpho-dynamics

4. Indicators

13 variables	10 variables
Indicator species (monitoring data)	Indicator species (monitoring data)

Figure 2. The relationship between the policy objectives and the indicators for the North Sea ecosystem.

Identification of the ecological indicators

The process of identifying the ecological indicators for the North Sea started with the analysis of the existing Water and Nature Conservation policies made by the ministries of V&W and LNV respectively (see Figure 2). The Water policy recommendation focuses on the maintenance of a sustainable ecosystem in the North Sea, tolerating human activities that would not hinder the normal ecological functioning of the ecosystem. The Nature policy recommendation focuses on maintaining the wildlife and biodiversity in the ecosystem.

The existing tools (AMOEBE and NDT) were analysed and integrated to cover the main issues of the policy statements. These issues include optimum biodiversity and sound ecological functioning of the ecosystem. Because the existing tools (AMOEBE and NDT) have a common quality of describing the ecosystem, they were analysed and integrated for the purpose of identifying the ecological indicators.
During the integration of the Water and Nature policies, the concept of biodiversity (a central theme for the Nature policy) was extended to include not only species diversity but also community diversities and functional diversities (habitat, ecotypes) in the North Sea. As well as the natural processes of hydro- and structural dynamics, energy transport patterns were used as elements for identification and selection of ecological indicators. For the analysis and description of the functional aspects of the ecosystem a new set of indicators was chosen.

Quality controls in the designing of the indicator system

Every stage in the process of identifying the indicators was analysed for the purpose of maintaining high quality and reproducible products. The relevance of the selected indicators to the policy recommendations and the ecosystem were thoroughly debated before acceptance. Workshops were held between the potential users of the indicators (policy-makers, managers, stakeholders) and researchers whereby general consensus on the methodology and the use of the indicators was reached (Duel *et al.* 1997).

The Nature and Water policies form the basis for the indicator systematic. The policy objectives were then interpreted into more concrete ecological concepts (biodiversity end ecological functioning). These ecological concepts were further described on the basis of the characteristics of the North Sea ecosystem. The relationships between the ecosystem characteristics were used to identify appropriate indicators and the subsequent indicator species for the ecosystem. It was realised during the design that changess in the ecosystem can only be brought into focus when indicators are developed which define the relevant and characteristic processes and structural characteristics of the ecosystem concerned. The following general characteristics of an ecosystem are based on the various organisational levels within the ecosystem and the associated functional aspects which define organisational levels:

species, both at individual level (number of species) and populations level (numbers of single species);
species groups and ecological communities: composition, structure and succession;
productivity of the various trophic levels;
structure of the food network: the food chains within an ecosystem and the inter-relationships, transverse connections and contacts;
hydro-morphodynamics: processes which cohere with water movements and sediment management that are also controlling elements for the creation of environmental conditions in which species and ecological communities can develop;
ecotopes: parts of an ecosystem which can be distinguished on the basis of hydromorphological factors which influence the occurrence of certain species or ecological communities.

Integration of the policy themes
In the integral evaluation system, the policy theme of conservation of biodiversity is coupled with the ecosystem characteristics, ecological community and ecotopes. The outcome is the following types of diversity which were used as bases for the development of biodiversity indicators:

- species diversity (inclusive genetic variation);
- diversity in species groups and ecological communities;
- diversity of habitat and ecotopes.

Although ecological processes are undoubtedly influential to the biodiversity of the ecosystem, indicators dealing with these processes are not included in the interpretation of biodiversity. The influence of ecological processes on biodiversity is based on the development of habitats, species, species groups and ecological communities. The inclusion of ecological processes when defining biodiversity will result in all ecological components being incorporated in diversity, which will result in a significant overlap with ecological functioning, which in turn results in the ecosystem acquiring a non-transparent structure.

The policy theme of **healthy ecological functioning** is evaluated using indicators which are linked to the following ecosystem characteristics:

productivity;
structure of the food network;
hydro and morphodynamics.

There are distinct links between biodiversity and ecological functioning. In the evaluation system, ecological functioning and biodiversity are specified from various standpoints. In the integral evaluation system the interfaces of both themes are expressed using a common set of system indicators.

The policy theme of **ecologically responsible use** is principally under discussion in the Water policy via the route of integral water management in which the ecological values for the North Sea and the economical values of the utilisation are weighed up against each other. The following utilisation functions are dealt with for the North Sea: fishery, shipping industry, recreation, military activities, mining industry, sand excavation and supplementation, land reclamation and infrastructure. This policy theme deals with keeping the balance between the impact of human activities on the ecological quality of the ecosystem and on biodiversity and the ecological functioning of the system. With regard to the indicators for ecologically responsible usage an overlap exists between biodiversity and ecological functioning. The indicators for describing the ecology-conscious usage are placed in a different category of indicators related to usage.

Basic selection criteria for the indicators

The final selection of the indicators and indicator parameters is based on a set of criteria which include:-

a. Criteria for the selection of indicators

- the indicators must be relevant to both the Water and Nature policies;
- the relationship between indicators and ecosystem characteristics must be unambiguously expressed;
- the indicators are quantified by one or more indicator parameters;
- in the indicator systematic, a distinction must be made between system and utilisation indicators;
- the total set of indicators provides the most comprehensive image of the North Sea's ecosystem;
- only indicators and indicator parameters which comply with the selection criteria will be included in the indicator system.

b. Criteria for the selection of indicator parameters

- the indicator parameter must have a significant relevance with the Water and Nature policies.
- the indicator parameters must have a distinct relationship with the process and/or structural characteristics of the North Sea ecosystem;
- one or more indicator parameters must be capable of making the indicator operational;
- the set of indicator parameters must be capable of providing a total picture of the quality of the North Sea ecosystem.

The following technical requirements are very relevant for the selection of the indicator parameters:

1. *Measurability:* the quality of the indicator parameter must be able to be determined based upon field data and/or model data. Information about the indicator parameters in the form of historic data and time-series is also an advantage.

2. *Unambiguity:* the direction in which an indicator changes must be unambiguous for the direction in which the ecosystem changes.

3. *Sensitivity*: the indicators must be able to perceive gradual changes in the ecosystem; a distinction must be made between natural fluctuations and changes due to human activities. The trends and indicator parameters must not have a broad tolerance for changes in environmental factors or ecological processes.
4. *Broad relationships* with existing evaluation systems is also an advantage.

The selected indicators for the North Sea
Indicators are developed based upon the various characteristics of the ecosystem (see Table 1).

The indicators are made operational by using one or more indicator parameters. The indicator parameters are ecological quantities or units (indices) derived from data on the parameters. The quality of the indicator parameter is determined using field and model data. By using these data, it is therefore possible to carry out policy evaluations both in advance (policy analysis) and in retrospect (monitoring). It is essential that reference points or a time-frame be defined for evaluation of the quality of the indicators. Reference points can be classified into:

- more or less natural reference, based on system definitions of more or less undisturbed situations in the past or comparable systems elsewhere;
- target value, based on a situation which is derived from the natural reference, taking specific social prerequisite constraints into consideration (such as safety, maintaining existing infrastructure and such like);
- standards, values established by the policy and which must be complied with;
- "base-line", a situation from the past which concerns impact caused by human actions and which serves as a reference point for the evaluation of the current situation and future planned developments; if data is only available for the current situation this can function as a baseline for the evaluation of future planned developments.

Using these reference points, a background can be created which can be used to describe the current quality of the ecosystem as well as recent developments and future developments in the ecosystem.

The integration of policy recommendations and characteristics of the ecosystem resulted in the identification of 23 indicators for the NCP ecosystem (see Table 1). Further development of the individual indicators was strongly based on the available knowledge of the indicator parameter.

As the first step in the development of a workable set of ecological indicators, 13 indicators were selected based on a pragmatic set of criteria. These criteria involved both administrative and technical qualities of the indicators. The administrative criteria were based on the qualities necessary for the use of the indicators for management purposes. The technical criteria is based on the technical requirements necessary for the development of the indicators. The evaluation system has a hierarchic structure, in which the following levels are distinguished in descending order: policy themes; ecosystem characteristics; indicators; indicator parameters; and basic data.

Table 1. GONZ Evaluation System Diagram

Policy themes	Ecosystem-characteristic	Indicator	System indicator parameters	Utilisation indicator parameters
biodiversity	species	plankton species diversity	•phytoplankton: average number of species •mesozooplankton: Simpson's index	•phytoplankton: average number of species (e) •mesozooplankton: Simpson 's index (e)
		macrobenthos species diversity	•diversity macrofauna: •number of species •Shannon-Wiener index •Simpson's index •relative abundance of most dominant species	
		macrobenthos population	•Quahog/Islandic cyprine density •Masked Crab/Helmet Crab density •starfish density	•Quahog/Islandic cyprine density (v) •Whelk density (s,x) •starfish density (v)
		fishes species diversity	•Simpson's fish fauna index •Simpson's fish fauna per length classification index	•Simpson's fish fauna index (v) •Simpson's fish fauna per length classification index (v)
		salt water fishes population	•Stingray:fishery mortality and spawning biomass •Fint: spawning biomass	•Herring: fishery mortality and spawning biomass (v) •Cod: fishery mortality and spawning biomass (v) •Plaice: fishery mortality and spawning biomass (v) •Stingray: fishery mortality and spawning biomass (v) •Fint: spawning biomass (i)
		coastal and sea birds species diversity	•Simpson's gulls and sterns index (breeding birds) •Herring gull: number of breeding pairs •Mediterranean gull: number of breeding pairs	
		coastal and sea bird population	•Sandwich tern: number of breeding pairs and number of fully-fledged young birds per breeding pair •Kentish plover: breeding pairs •Common scoter: number of mating days in winter	•Sandwich tern :number of breeding pairs and number of fully-fledged young birds per breeding pair (v,x) •Kentish plover: breeding pairs (r) •Lesser black-backed gull: number of breeding pairs (v) •Common scoter: number of mating days in winter (v)
		marine mammals population	•Porpoise: number of animals •Common seal: number of animals	•Porpoise: number animals (v,x) •Common seal: number of animals (x)

		distribution area of marine mammals	•Porpoise: distribution area •Common seal: resting area	•Porpoise: distribution area (s,v,m) •Common seal: resting area (r,m)
	species groups and ecological communities	plankton community structure	•phytoplankton: •length-distribution •ratio of densities between flagellates and diatoms •total duration of flowering of *Phaeocystis, Noctiluca* and *Dinophysis* •zooplankton: not yet specified	•phytoplankton: •distribution of length (e) •density ratios between flagellates and diatoms (e) •total duration of *Phaeocystis, Noctiluca* and *Dinophysis* flowering (e) •zooplankton:not yet specified
		macro-benthos community structure	•ratio density r-and K-strategists	
		fish community structure	•average weight of fishes •biomass percentage fishes >25cm in total fish biomass	•average weight of fishes (v) •biomass percentage fishes >25cm in total fish biomass (v)
	ecotopes	surface of ecotopes	•*Spisula* banks area in ecotope shallow coastal zone •undisrupted gravel banks area •area of undisrupted stone ecotopes in the area of Texelse Stenen	•*Spisula* –banks area in ecotope shallow coastal zone (v) •undisrupted gravel banks area (v,z) •area of undisrupted stone ecotpes in the area of Texelse Stenen (v)
Ecologically functioning	productivity	primary production	•primary production by phytoplankton	•primary production by phytoplankton (e)
		secondary production	•secondary production by copepods •secondary production by benthos	
		tertiary production	•somatic fish production	•somatic fish production (v)
		decomposition	•starfish density •Masked Crab/Helmet Crab density	•starfish density (v)
	food network-structure	staple food	•copepods density: *Calanus finmarchicus* *Temora longicornis* •*Spisula subtruncata* density •Small sand eel: fishery mortality and spawning biomass •Herring: fishery mortality and spawning biomass	•*Spisula subtruncata* density (v) •Small sand eel: fishery mortality and spawning biomass (v) •Herring: fishery mortality and spawning biomass (v)
		top predators	•Cod: fishery mortality and spawning biomass	•Cod: fishery mortality and spawning biomass (v)

			•Sandwich Tern: number of breeding pairs and number of fully-fledged young birds per breeding pair •Porpoise: number of animals •Common seal: number of animals	•Sandwich Tern: number of breeding pairs and number of fully-fledged young birds per breeding pair (v,x) •Porpoise: number animals (v,x) •Common seal: number of animals (x)
		complexity of food network	as yet no indicators proposed	
		trophic structure of macrobenthos-community	•macrobenthos food groups index (ITI)	
		trophic structure of fish population	as yet no indicators proposed	as yet no indicators proposed
	hydro and morpho-dynamic	dynamic ecotopes area	•sand bar area	•sand bar area (z,i)

Examples to explain the use of the indicators

Example 1: Marine fish population

<u>Relevance and sensitivity of the indicator</u>

Fisheries strongly influence the fish populations in the North Sea, not only the commercially attractive species such as cod, herring, plaice and sole, but also the commercially less important sharks and rays. Ecological sustainability means that the viable fish populations must remain in existence and conservation of biodiversity and ecotopes must advance. The commercial species are the most significant for the fisheries, of which the viable species must also remain in existence. Ecological sustainability and fishery concerns are equally significant for the commercial species. This does not apply for commercially uninteresting species, for which only ecological sustainability is important.

For policy-making purposes the fish population is an obvious group. The situation in which fish stock find themselves makes a statement about both the quality of the North Sea ecosystem and about the utilisation of the ecosystem by the fishery. The population development of the various fish species can be seen as an indicator for the ecological quality of the North Sea. The Water policy is geared towards sustainable development of the water system and a durable utilisation. Sustainability is pivotal for ecological quality and combines both the Nature concerns and the fishery concerns.

<u>Indicator species</u>

The following species have been chosen as indicator species: cod, herring, sand eel and plaice as commercial species; stingray for the non-commercial species. Herring is a pelagic species; of the demersal species cod live and plaice live on the seabed. The different feeding habits are also represented: herring eat zooplankton, plaice eat benthos, cod eat fish and benthos, sand eel eat copepods and worms, and the stingrays eat sand eel and crustaceans.

For the indicator 'population marine fishes,' the population parameters of spawning biomass and fishery mortality are used as indicator parameters. Fish species which are characteristic elements of the fish fauna and at the same time reflect the clearly distinguishable form of fishery make up the indicator species (herring, cod, plaice, sand eel and stingray (susceptible to fishery pressure).

Data compilation and processing methodology
Mortality and spawning biomass of the four species are measured. The monitoring frequency is once per year. There are very few measurements for the stingray.

Developments and trends in previous years
In previous decades, the fish populations in the North Sea have been intensively fished, possibly with the exception of the sand eel. The situation appears to have stabilised somewhat in the last few years and in a few cases a slight recovery appears to have taken place.

The indicator and the current quality of the North Sea
Table 2 presents an image of the current spawning biomass and fish mortality for the four commercial species, with regards to the concern levels proposed by the ICES in 1998. In previous decades the fish mortality of herring, cod and plaice exceeded the concern levels. The sand eel displays a healthy population; herring, cod and plaice are on and around the safe biological minimum (MBAL). The stingray is suspected to be outside the biologically safe limits.

The ICES proposed levels of minimum spawning existence from 1998 (Bpa in tons) and maximum fisheries mortality representation (Fpa) as well as the decline in percentage per year which complies with the proposed fisheries mortality.

Table 2. Indicator parameters for marine fish populations in the North Sea.

Fish type	Bpa	Fpa	%
Herring	800.000	0.30	26
Cod	150.000	0.65	48
Plaice	300.000	0.30	26
Sand eel	600.000	-	-
Stingray	-	-	-

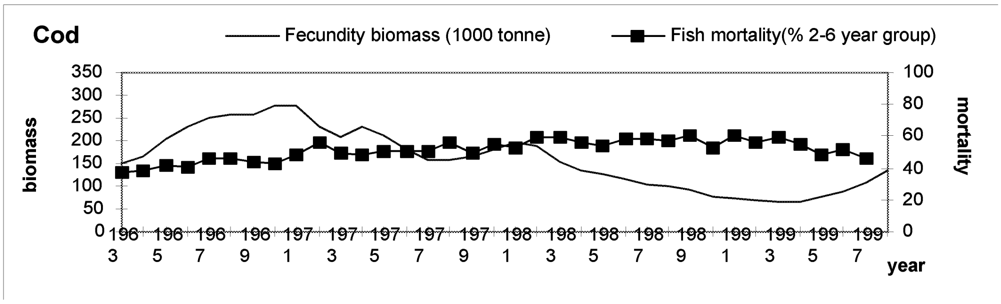

Figure 3. Fecundity biomass and fish mortality for cod.

Example 2 : Sandwich tern *(Sterna sandvicensis)*

Relevance
The Sandwich tern at sea is an indicator of the availability and quality of food. Sandwich terns forage in the Dutch coastal area (to a depth of 20 m) and secure their food by diving from low heights to depths of more than 1 metre. Their food comprises mainly small fish species; along the Dutch coast this is primarily sprat, young herring and sand eel. Further research into the ecology of foraging Sandwich terns is needed, in particular into the impact of water quality on the presence and their ability to catch the food.

As a breeding bird, the species can be used as an indicator for the availability of food in combination with the quality of the foraging areas in the North Sea. The breeding habitat required by this species, slightly

overgrown sandy plains, is constantly under pressure from changes and disturbances. The Sandwich tern broods in colonies in the Scheldt estuary and the Wadden Sea.

The number of Sandwich terns in the Netherlands is largely determined by the availability of breeding areas in combination with the quality of the foraging areas in the coastal area of the North Sea, including the amount of fish, the size of these fish and the quality (accumulation of toxic substances). The numbers of breeding pairs are principally influenced by the availablility of suitable breeding biotope. In the Netherlands, in particular the Friesian Islands, a limited amount of breeding biotope is still present, but this is unsuitable due to excessive recreational pressure. An insufficient availability of food in the coastal area can also lead to a reduction in the number of terns that can breed. If this is incidental then it has no impact on the total population range, as Sandwich terns have a long life span.

This bird migrates to Africa in the winter period and the numbers in the Netherlands can be influenced by the situation there. This is why further research into structural changes must always be carried out in order to discover the true cause of population variations.

Trend and current situation

Sandwich terns are virtually only seen along the coast (Stone *et al.* 1995). The distribution is associated with the availability of nesting grounds. Outside the breeding seasons terns normally live in large groups at sea. Figure 4 shows the trend in numbers of Sandwich tern breeding pairs in the Scheldt estuary sector. The trend displays an obvious dip in 1991. This dip was primarily due to the fact that a large section of the "Scheldt population", in Zeebrugge in particular, bred in Belgium. After 1994 the numbers in Zeebrugge declined once more. A section of the breeding birds relocated once more to the Scheldt, but it also became apparent that the total Scheldt population began to grow again (Meininger *et al.* 1999). At the end of the nineties the Scheldt breeding population comprised around 4,500 birds. This is more than the RAMSAR-1%-standard (Rose and Scott 1994).

The number of Sandwich tern breeding pairs in the Wadden Sea follows a slightly rising trend with a dip in 1996. This dip can possibly be explained by a sparse fish availability (herring types), probably as a result of a natural fluctuation. The majority of adult birds then skip a year of breeding, although young Sandwich terns try anyway. (Stienen and Brenninkmeijer 1997).

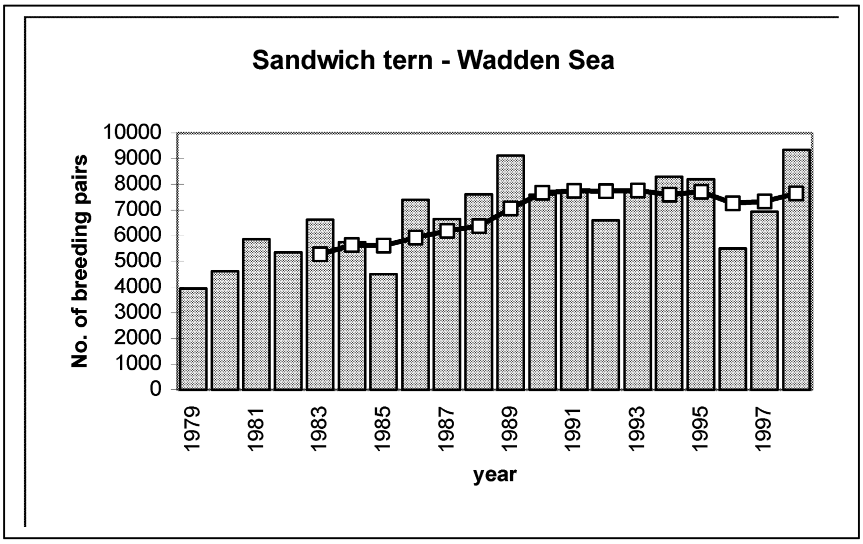

Figure 4. Trend in numbers of breeding pairs of Sandwich terns in the Wadden Sea area, 1979-1998. The black line represents a calculated trend.

Example 3: Trophic structure macrozoobenthos

Relevance and sensitivity
For seabed animals, four different forms of food absorption are recognised. These forms are considered typical to specific forms of food availability, whereby human actions can influence this availability. An index can be calculated using the grouping of species into these four types of food absorption, the Infaunal Trophic Index (ITI). Compared with other indicators such as diversity, biomass, density and level of sedimentation of organic matter. the IT Index is the most sensitive to changes in the structure of the macrozoobenthos community.

Indicator species
A selection is made from of all microzoobenthos species which with their specific manner of feeding belong to one of the groups:

1. Suspension feeders: animals which feed on suspended matter, thus floating in the water. This takes place with filter systems or tentacles, fans, arms or a mucous net.
2. Interface feeders: these animals can extract food both from the water and the seabed.
3. Surface deposit feeders: species which are specialised in the detritus (dead organic matter) which lies on the seabed.
4. Subsurface deposit feeders: these animals live off the detritus that is buried in the seabed. Normally a large amount of sediment passes through the intestines of these animals.

Therefore these are not omnivores, predators or herbivores. Subsequently all scarce species are dropped. Ultimately only a small percentage of the animals is left, which is included in the ITI calculations. The IT Index is based upon the total number of species found which belong to one of the stated feeding methods in the selection..

Compilation and processing of the data
When it is determined which animals are to be included in the calculation, from every location or sample, the index can be calculated, using a formula. The multiplication factors 0, 1, 2 and 3 are input in order to obtain a scale distribution. If the result is around 100, then the suspension feeders are dominant for the selected species and the environment is considered stable and barely disrupted. If the result is around 0 then the subsurface deposit feeders are dominant and a large disturbance is probably taking place, almost certainly as a result of human actions.

The ITI can be calculated annually using the microzoobenthos monitoring programme (MWTL). To this end the index is calculated for each sample, after which the median value is presented per sub-sector.

Developments in previous years and current situation
The development of the trophic structure macrozoobenthos indicator in the period (1991-1998).

Oyster grounds (north):
In general relatively high IT indices have been measured in the most northerly sub-sector of the NCS, in particular from 1991-1993, and to a lesser extent in the final years of research, where a drop in the index was perceived. The lowest values of the IT Index in this sub-sector were measured in 1997.

Oyster grounds (south):
In the southern sector of the oyster grounds relatively high figures for the IT Index have been registered, however on average these are slightly lower than in the North. Furthermore, a decline can be seen for the years 1992-1994, although the IT index remained reasonably stable (65-74) between 1995 and 1998 in this sub sector.

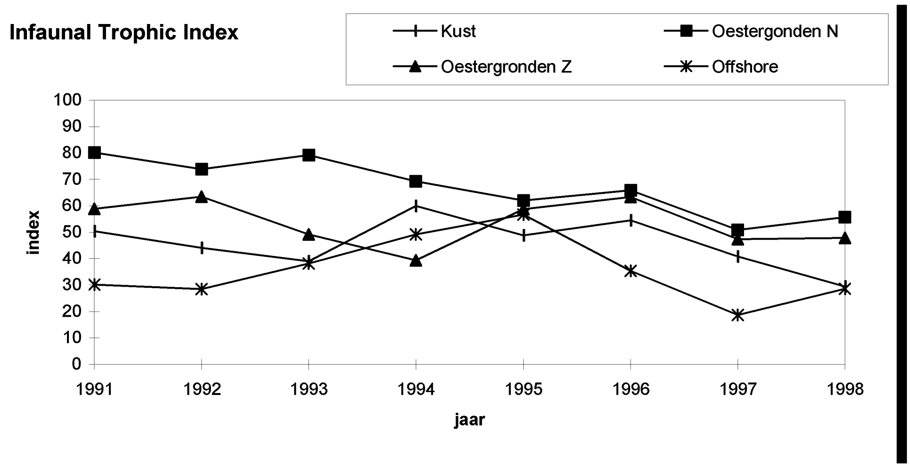

Figure 5. The development of the average ITI in different parts of the North Sea.

Offshore area:
On average a low ITI was found in the offshore area in the years 1991/1992; after an increase up to 1995 a decline was observed during the last three years (1995-1998).

Coastal area:
The widest distribution of the ITI of all four sub-sectors has been observed in the Dutch coastal area. The drop in the index along the coast between 1995 and 1998 is in line with the trend for the offshore area.

The ITI in all four areas shows a drop in the last years. It is striking that the development in the oyster grounds (north and south) shows a conflicting trend. The average spatial distribution of this indicator in the period 1991-1998 shows a high mean ITI in the oyster grounds and at two stations along the coast. The offshore sector shows significantly lower ITI's between 1991 and 1998. It must be kept in mind that the calculation of the index between 1991 and 1994 was carried out using five sub-samples per location, whereas since 1995 only one sample per location is used.

Conclusions

Having based the development of the indicator systematic on the relevant processes and structural characteristics of the North Sea ecosystem, the foundations were laid for the development of indicators for the integral evaluation of the water and nature policy objectives which include:-

- biodiversity
- ecological functioning
- sustainable use of the North Sea ecosystem.

The significant additional benefit of the integral indicator system is that in contrast to the existing evaluation systems (AMOEBE and NDT), the indicator system is based on species, ecological communities, ecotopes, productivity, food network structure, hydro- and morpho-dynamics. This links the assessment and evaluation of the ecological qualities of all sorts of water systems. It creates a better picture of the possible changes in the quality of the ecosystem. In the previous evaluation systems (AMOEBE and NDT), no obvious link was found between the parts of the ecosystem (the species) and the various human activities on the North Sea. The opportunity exists within the indicator evaluation system to evaluate or assess the ecological impacts of human activities in relation to biodiversity and ecological functioning. The impacts of specific human activities such as fisheries could be directly described by using the related (fish and macrozoobenthos) indicators.

The existing monitoring programmes in the Netherlands can supply sufficient information in order to quantify a large number of indicator parameters. In a few cases alteration of the existing monitoring programmes or establishment of an additional monitoring programme is desired.

The development process of the indicators has initiated a communication network between researchers, managers and policy-makers. This communication channel has never been as gainfully used as in the GONZ project. The people involved understand each other and the possibility exist of a collective decision on single sectoral problems as fisheries, sand extraction and eutrophication.

The difficulties with the North Sea in using the indicator systematic is the size of the water mass. The North Sea is big and natural processes play a leading role in the day-to-day changes in the ecosystem. Changes due to humans are mostly local and could be in some way carried over broader areas but with minimum impacts, because the sea has a replenishing component which ensures the cleaning up of the ecosystem to a more balanced and organised state as dictated by the prevailing conditions. Further work in the GONZ project is now being carried out to quantitatively differentiate the changes caused by natural forces from those caused by human activities. The products of this work could be used to reduce some of the uncertainties around the North Sea ecosystem and its behaviour.

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6. Catchment to Sub-Regional Assessment Tables

Regional Assessment Tables 1. North West Africa (Morocco) *by Maria Snoussi*

Table RA 1.1. North West Africa (Morocco): major coastal impacts/issues and critical thresholds

*Overview and qualitative ranking, 1 = minimum, 10 = maximum

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning)	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data sources
Erosion	a. Atlantic coast b. Mediterranean coast	No specific threshold are available	a. Exceeded. Estimated erosion between 0.05 and 0.4 $x10^6$ton/year . The construction of dams has reduced the Sebou sediment flux of nearly 95%. b. Exceeded. Observed coastal erosion of. 0.06 $x10^6$ton/year 2-5m at Tangiers bay due to the port extension. 94% of the Moulouya sediment flux are trapped behind dams.	a. 7 b. 9	Snoussi *et al.* (1990) Charrouf (1991) Probst & Amiotte-Suchet (1992) Zourarah (1994) Haida (2000)
Sedimentation (marine sedimentation due to reduced freshwater inflow or from land -use changes)	Atlantic coast and Mediterranean coast	Not known	Marine sedimentation exceeds fluvial sedimentation in many sites of both the Atlantic and Med. coasts, due to the impoundment of water flows and the reinforcement of the marine influence. The littoral drift is estimated between 0.25 and 8 $x10^6$ton/year. All ports and estuaries are silted. $0.7x10^6m^3$ of sediments are deposited annually in the Sebou estuary. This affects navigation channels causing dredging. The inlets of lagoons are periodically closed.	9	Charrouf (1991) Snoussi *et al.* (2001)
Eutrophication	Atlantic & Med.	Actual limit CNP ratio not known. Excessive algal rowth.	Occurrence of low oxygen and high values of nitrogen in estuaries and lagoons. Increasing of frequency of algal blooms	8	Lefebvre *et al.* (1996) Benasser (1997)

Table RA 1.1. North West Africa (Morocco), continued.

Coastal Impact/Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution Human pathogens Heavy metals Pesticides Hydrocarbons	a. Med. coast b. Atlantic	WMO norms and standards. Baselines concentrations of unpolluted soils of the basin	a. Exceeded, loss of biodiversity. Zn, Cd,Hg , BOD, DOC and pesticides are monitored in the the framework of MedPol Programme. Occurence of red tides twice a year b. Increasing backround level of heavy metals by a factor of 2 in most areas. High values in biota mainly bivalves	a. 8 b. 9	MAP Technical Reports Series Snoussi (1992) CNE (1995) Cheggour (1999)
Aquatic weeds (usually water h) also include invasive plant species	Med. Coast	Presence (*Caulerpa*)	Exceeded	7	MAP Technical Reports Series
Biodiveristy loss (Loss of biological function)	a. Med. Coast b. Atlantic	Change in species composition and abundance	a. Exceeded. Loss of marine turtles (5000/year), monk seals, and red coral reefs due to overexploitation and pollution. Complete loss of *Posidonia.* b. Declining of fishery stocks, lobsters (Dakhla Bay), octopus and carpet-shells.	a. 7 b.9	MAP Technical Reports Series Menioui (2001)
Salinisation	Coastal plains of Moulouya, Sebou, and Oualidia	Not known. Excess of salts in wells (water for drinking and irrigation)	Exceeded in most of the irrigated coastal plains, due to over-extraction of groundwater, over-use of fertilizers and droughts.	9	Moussaoui (1994) El Mandour (1998)
Human health issues		Presence of disease	Close to threshold in some areas	6	

Table RA 1.2. North West Africa (Morocco): DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact versus catchment size class

P = progressive, **D** = distinct

Driver	Pressures	State change qualitative index	Impact on the coastal system	Time scale
		Medium basins 10 000 – 200 000 km^2		
Damming	Modification of hydrological regime (runoff)	**major**	Sedimentation Erosion Biodiversity loss Salinisation Human health issues	**D**
	Modification of morphological processes	**major**	Sedimentation Erosion	**P**
	Modification of water quality	**major**	Eutrophication Pollution Human health issues Biodiversity loss	**D**
	Dam operation	**medium**	Flood	**D**
Deforestation	Modification of vegetation cover Increasing load of fluvial suspended sediments	**major**	Erosion/Sedimentation Eutrophication Biodiversity loss	**P**
Agriculture	Modification of water quality Waste/nutrients (excess fertilizers)	**major**	Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**
	Modification of vegetation cover	**major**	Sedimentation Eutrophication Biodiversity loss	**P**
	Modification of morphological processes	**major**	Sedimentation Erosion	**P**

Table RA 1.2: North West Africa (Morocco), continued.

Driver	Pressures	State change qualitative index	Impact on the coastal system	Time scale
Agriculture/ continued	Modification of water quantity (surface or ground water) through irrigation Increase of water extraction	**major**	Sedimentation / Erosion Salinisation	**P**
Urbanisation	Modification of water quality: Increase of nutrients, metals and BOD-rich waste effluents. Increasing water extraction	**major**	Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**
Navigation	Dredging. Waste effluents. Ballast. Coastal engineering works	**medium**	Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P/D**
Aquaculture	Increase of nutrients DBO-rich waste effluents	**minor**	Eutrophication Pollution Introduction of exotic species	**P**
Industrial waste	Modification of water quality and quantity	**major**	Eutrophication Pollution Human health issues Biodiversity loss	**D** (spill) **P** (bioaccum -ulation)
Climate change	Modification of hydrological regime	**minor**	Sedimentation Erosion Biodiversity loss Salinisation Human health issues	**P**
	Accelerated of sea level rise	**medium**	Erosion Flood / Saline intrusion Biodiversity change	**P**
Mining (sands and gravels from rivers and beaches)	Sediment budget alteration Changes of the morphological processes	**medium**	Erosion/sedimentation Biodiversity loss	**P**

Tables RA 1.3 & 1.4. North West Africa (Morocco): Linking coastal issues/impacts and land-based drivers at the catchment and sub-regional scale.

Overview and qualitative ranking on catchment and sub-regional scale: 1 = minimum, 10 = maximum

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		Sebou and Moulouya	Impact Category		
Erosion	Damming	Traps sediment from catchment	9	⇑	CNE (1995) Lahlou (1996) Haida (2000)
	Deforestation	Energy demand	6	⇑	
	Agriculture	Overgrazing, extension of farms	8	⇑	
	Population & urbanisation growth	Increasing demand for space	6	⇑	
	Climate change	Short-term climate variation	?	?	
Sedimentation	Damming	Silting up of reservoirs Reduced flows allowing marine sediments to accumulate	9	⇑	Charrouf (1991) Snoussi *et al.* (2001)
Eutrophication	Sewage	Non-point disposal	9	⇑	
	Agriculture	Leaching of nutrients	8	⇑	
Pollution	Industrial and domestic waste	Poor disposal of waste, few treatment plants	8	⇑	
Aquatic weeds	Active human introduction	Accidental by fishermen	6	⇑	Menioui (2001)
	Sewage	Non-point disposal	7	⇑	
	Agriculture	Leaching of chemicals	6	⇑	
Biodiversity loss	All drivers listed above	Complex interplays of all factors	8	⇑	GERM (1994)
Salinisation	Drought Sea-level rise Urbanisation Agriculture	Over-extraction of coastal groundwater Over-use of fertilizers Increasing evaporation	9	⇑	Moussaoui (1994) El Mandour (1995)
Human health issues	Sewage	Disposal of human waste	8	⇑	

Table RA 1.6. North West Africa (Morocco): Scientific and/or Management RESPONSE to coastal impact/issues.

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional (North West Africa)	
	Scientific	**Management**	**Scientific**	**Management**
Sebou	Atlas du Sebou (1970) Etat de qualité des Ressources en eau au Maroc (DRPE 1998). Diagnose de l'Etat de l'environnement dans le bassin du Gharb (Benasser 1997) Bilan des flux du Sebou (Haida 2000)	The 'Office Régional de Mise en Valeur Agricole du Gharb' (ORMVAG) is in charge of the management of the Sebou basin. The Waters and Forests department and the department of Environment have carried out many project in the basin among them the rehabilitation of the Sebou Basin Project.		
Moulouya	Many reports and papers on how to combat siltation of dams, soil erosion and salinisation in the basin	Aménagement du bassin de la Moulouya (Eaux et Forets, in press)	- Med Campus Project (UE). *« Gestion des réserves d'eau souterraine dans les zones affectées par la salinisation ».1994.* -Avicenne Project (UE)*: «Development of water resources management tools for Problem of seawater intrusion and contamination of fresh-water resources in coastal aquifers ». 1995-1999.* -FICU Project: (***F****ond* ***I****nternational de* ***C****oopération* ***U****niversitaire): 'Gestion et protection des ressources en eaux dans les plaines semi-arides au Maroc et en Tunisie.2000-2002'.* MATER Project ADIOS Project	Guidelines for Integrated Coastal Zone Management in the Mediterranean Region (UNEP, 1995) L'eau dans le bassin Mediterranéen (Economica) (Margat 1992)

Table RA 1.7. North West Africa (Morocco): Hot spots of land-based coastal impact, gaps in understanding, and an overview of issues to be addressed in future research.

River catchment	**Hot spot Catchment scale**		**Hot spot Sub-regional/ Country scale (e.g., Maputo Bay, SADC region)**		**Hot spot Regional scale**	
	Key issue, trend and gaps	Scientific approach	Key issues, trend and gaps	Scientific approach	Key issues, trend and gaps	Scientific approach
Sebou and Moulouya	*Key issues:* 1. Erosion/sedimentation 2. Pollution/health issues 3. Salinisation 4. Biodiversity loss *Trend:* Increasing *Gaps:* Additional data are required to improve the calculations of natural and anthropogenic fluxes, to better understand the functioning of the estuarine zones and to predict the future potential changes.	Monitoring water and sediment fluxes, and water quality parameters. Development of adequate environmental indicators and precise critical thresholds. Establishment of socio-economic profiles in relation to population changes, industrialisation, agriculture and forestry, and development of economic cost-benefit analysis. Development of numerical models and GIS in relation to future land-use and climate changes, easily readable by managers.				

Regional Assessment Tables: 2. West Africa *by I. Niang Diop, A. Kane, C. Gordon and G. Umoh*

Table RA 2.1. West Africa: Major coastal impacts/issues and critical thresholds.

Overview and qualitative ranking: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category	References/ data source
Erosion	a. Volta b. Senegal c. Niger	a. Greater than $1.5x10^6$t/yr b. Greater than $1.5x10^6$t/yr c. Not known	a. Exceeded b. Not exceeded in terms of catchment influence c. Exceeded (not sure of cause)	a. 8 b. 5 c. 8	a. Gordon (1998) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996; Kane (1997) c. NEST (1989)
Sedimentation (referring to marine sedimentation due to reduced freshwater inflow or sedimentation due to inappropriate agricultural practices in catchment)	a. Volta b. Senegal c. Niger	a. 2 km of shoreline development over 10 years b. Marine sedimentation exceeding fluvial sedimentation c. Not known	a. Exceeded b. Exceeded c. Exceeded	a. 7 b. 9 c. 6	a. Gordon (1998) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996) c. NEST (1989)
Eutrophication (e.g., algal blooms)	a. Volta b. Senegal (potential issue) c. Niger	a-c. When CNP ratio becomes unbalanced, actual limit not known.	a. Exceeded due to presence of algal blooms (offshore and in coastal lagoon) b. Not exceeded c. Exceeded	a. 7 b. 4 c. 7	a. Entz (1969) b. UNEP (1999) c. NEST (1989)

Table RA 2.1. West Africa continued.

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category*	References/ Data source
Pollution Hydrocarbons (1) Heavy metals (2) Pesticides (3)	a. Volta (3) b. Senegal (3) c. Niger (1, 2) d. Cross (1, 2)	a-d. Generic critical thresholds can probably be derived from literature, but currently site Specific values are not available	a. Exceeded, loss of biodiversity b. Not known c. Exceeded (oil pollution) d. Exceeded (oil pollution)	a. 6 b. – c. 8 d. 9	a. Czernn-Chudenitz (1971); Amoah (1999) b. - c. NEST (1989); CRP (1999) d. CRP (1999)
Aquatic weeds, including invasive plant species	a. Volta b. Senegal c. Niger (nypa) d. Cross (nypa)	a. Presence b. Presence c. Presence d. Presence	a. Exceeded b. Exceeded c. Exceeded d. Exceeded	a. 7 b. 9 c. 7 d. 9	a. De Graft-Johnson (1999) b. Cogels *et al.* (1993); BDPA- SCETAGRI *et al.* (1995); Matera & Malaisse (1999) c. CRP (1999) d. AKS (1989)
Loss of Habitat/biodiversity (Loss of biological function)	a. Volta b. Senegal c. Niger (mangroves loss) d. Gambia (mangroves loss)	a-c. Change in species composition and abundance	a. Exceeded b. Exceeded c. Exceeded	a. 7 b. 8 c. 7	a. Gordon (1999) b. Bousso (1992); Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); c. Ibeanu (2000)
Salinisation	a. Senegal b. Niger c. Cross	a. Not known, because the system is complex b. Not known c. Not known	a. Not exceeded b. Exceeded c. Exceeded	a. 5 b. 7 c. 7	a. BDPA-SCETAGRI *et al.* (1995); Diouf (1998); Pages *et al.* 1987; Debenay *et al.* (1994) c. Ibeanu (2000)

Table RA 2.1. West Africa, continued.

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category*	References/ Data source
Human health issues	a. Volta (Invasion of snails/water related diseases) b. Senegal (Invasion of snails/water related diseases) c. Niger (water related diseases) d. Cross (water related diseases)	a. Presence of disease b. Presence of disease c. Presence of disease d. Presence of disease	a. Exceeded b. Exceeded c. Exceeded d. Exceeded	a. 8 b. 8 c. 7 d. 7	a. Derban (1999) b. Handschumacher *et al.* (1992); Talla (1993); Niang (1999) c. NEST (1989) d. Ibeanu (2000)

Table RA 2.2. West Africa: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact *versus* catchment size class

NOTE: Expertise and information for medium and small basins in sub-region West Africa was not available for the workshop.

P = progressive, **D** = distinct

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km²	Medium basins	Small basins:		
Damming	Modification of hydrological regime (runoff)	**major**			Sedimentation Erosion Aquatic weeds Biodiversity loss Salinisation Human health issues	**D**
	Modification of morphological processes	**major**			Sedimentation Erosion	**P**
	Modification of water quality	**major**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**D**
	Dam operation	**major**			Flood	**D**
Deforestation	Modification of vegetation cover	**major**			Sedimentation Eutrophication Biodiversity loss	**P**
	Modification of morphological processes	**medium**			Sedimentation Erosion	**P**
	Modification of water quality	**major**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**

Table RA 2.2. West Africa continued.

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
Agriculture	Modification of water quality	**medium**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**
	Modification of vegetation cover	**major**			Sedimentation Eutrophication Biodiversity loss	**P**
	Modification of morphological processes	**major**			Sedimentation Erosion	**P**
	Modification of water quantity (surface or ground water) through irrigation	**minor**			Sedimentation Erosion	**P**
Human settlement/ Urbanisation	Modification of water quality	**major**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**
	Reduction ground water quantity (abstraction)	**medium**			Sedimentation Erosion	**P**
	Deterioration of human health (e.g. through sewage disposal)				Human health issues	**P**
Climate change	Modification of hydrological regime	**minor**			Sedimentation Erosion Aquatic weeds Biodiversity loss Salinisation Human health issues	**P**
	Accelerated of sea level rise	**medium**			Erosion Flooding Salinisation Biodiversity change	**P**

Table RA 2.2. West Africa continued.

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
Bush fires	Modification of water quality	**minor**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**D**
	Modification of vegetation cover	**medium**			Sedimentation Eutrophication Biodiversity loss	**D**
Industrialisation	Modification of water quality	**major**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**D** (spill) **P** (bioaccumu-lation)
Mining	Modification of water quality	**medium**			Eutrophication Pollution Aquatic weeds Human health issues Biodiversity loss	**P**
	Modification of hydrological regime	**medium**			Sedimentation Erosion Aquatic weeds Biodiversity loss Salinisation Human health issues	**P**
Fishing	Modification of water quality	**minor**			Pollution Biodiversity loss	**P**
Active human introduction of weeds	Modification of biodiversity	**medium**			Aquatic weeds Eutrophication Biodiversity loss	**P**

Table RA 2.3. West Africa: Linking coastal issues/impacts and land-based drivers at the catchment scale.

Overview and qualitative ranking on catchment scale: 1 = minimum, 10 = maximum

Coastal Impact Issues	Drivers	Local catchment = Volta: Motivation	Impact Category	Trend expectations	References/ Data sources
Erosion	Damming	Traps sediment from catchment	9	⇑	Kane (1997); Titriku (1998)
	Deforestation	Energy demand	6	⇑	
	Agriculture	Overgrazing; trampling by nomad cattle	8	⇑	
	Human settlement	3% population increase per year	6	⇑	
	Bush fires	Longer dry season results in fires destroying cover	6	⇒	
	Climate change	Short term climate variation	?	?	
Sedimentation	Damming	Reduced flows allowing marine sediments to accumulate	7	⇒	Gordon (1998)
Eutrophication	Human settlement (sewage)	Non-point disposal	10	⇑	Mackinnon (1958)
	Agriculture	Leaching of chemicals	6	⇑	
	Bush fires	Nutrient rich ashes carried into water	5	⇒	
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	Poor disposal of waste (point ans non-point)	7	⇑	Amoah (1999)
	Mining	Waste from mining	7	⇑	
	Fishing	Use of pesticides for fishing	6	⇓	
Aquatic weeds/ Invasive plants	Active human introduction	Florists Accidental by fishermen	7	⇑	De Graft-Johnson (1999)
	Human settlement (sewage)	Non-point disposal	7	⇑	
	Agriculture	Leaching of chemicals	7	⇑	
	Bush fires	Nutrient rich ashes carried into water	7	⇒	
Loss of habitat/ biodiversity	All listed drivers	Complex interplay of all factors	8	⇑	Gordon (1999)
Human health issues	Human settlement (sewage)	Indiscriminate disposal of human waste	8	⇑	Derban (1999)

Table RA 2.3. West Africa, continued.

Coastal Impact /Issues	Drivers	Local catchment = Senegal		Trend expectations	References/ Data sources
		Motivation	Impact Category		
Erosion	Damming*	Catchment derived sediment is trapped by damming	5	⇒	Diaw *et al.*, (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1995); Soumare (1996)
	Agriculture	Extension of rice farming in delta increased soil erosion	7	⇑	
Sedimentation	Damming*	Reduced river flows allow marine sediments to accumulate in estuaries	9	⇑	
Eutrophication	Damming*	Permanence of freshwater	4	⇑	UNEP (1999)
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Use of pesticides and fertilizers	-	⇑	
	Urbanisation	Sewage and solid waste	-	⇑	
Aquatic weeds/ Invasive plants	Damming*	Permanence of freshwater	9	⇓	Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); Matera & Malaisse (1999)
Loss of habitat/ Biodiversity	Damming*	Damming divided system into 2 separate ecosystems, i.e. fresh and marine. No estuarine - destroyed	8	?	Ibeanu (2000)
Salinisation	Drought	Natural. The anti-salt dam was constructed to prevent further upstream salinisation	5	⇑ (downstream part) ⇒ (upstream part)	Pages *et al.* (1987); Debenay *et al.*, (1994); BDPA-SCETAGRI *et al.* (1995); Diouf (1998)
Human health issues	Damming*	Created habitat for snails (on freshwater side) that affect the health of the coastal community	8	⇑	Handschumacher *et al.* (1992); Talla (1993); Niang (1999)
	Urbanisation	Sewage disposal	8	⇑	

* To prevent further upstream salinisation in the Senegal River (due to drought) a dam wall was erected. Damming divided the system into 2 separate ecosystems, i.e. fresh and marine. The estuarine ecosystem has been destroyed.

Table RA 2.3. West Africa, continued.

Coastal Impact Issues	Drivers	Local catchment = Niger		Trend expectations	References/ Data sources
		Motivation	Impact Category		
Erosion	Agriculture	Poor land management results in soil erosion	8	⇑	AKS (1989)
	Deforestation	Cutting down of trees expose the land and results in erosion	8	⇑	AKS (1989); NEST (1989); Okoh & Egbon (1999)
Sedimentation	Damming	Reduced river flows allow marine sediments to accumulate in estuaries	6	⇑	NEST (1989)
Eutrophication	Agriculture	Use of fertilizer	7	⇑	
	Urbanisation (sewage)	Non-point sources	7	⇑	
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Industrialisation	Petroleum production	9	⇑	NEST (1989); AKS (1989)
	Agriculture	Use of pesticides and fertilizers	7	⇑	NEST (1989)
Human health issues	Urbanisation (sewage)	Indiscriminate disposal of human waste	7	⇑	
Aquatic weeds, including invasive plants	Transport	Ballast water	7	⇑	
Loss of Habitat/ Biodiversity	All listed drivers	Complex interplay of all factors	7	⇑	NEST (1989) Ibeanu (2000)
Salinisation	?	?	7	⇑	

Table RA 2.3. West Africa, continued.

Coastal Impact/ Issues	Drivers	Local catchment = Cross		Trend expectations	References/ Data sources
		Motivation	Impact Category		
Erosion	Agriculture	Poor land management results in soil erosion	8	⇑	AKS (1989)
	Deforestation	Cutting down of trees expose the land and results in erosion	8	⇑	AKS (1989) Okoh & Egbon (1999)
Sedimentation	Agriculture	Poor catchment management results in soil erosion upstream and sedimentation in coastal zone	6	⇑	NEST (1989)
Eutrophication	Agriculture	Use of fertilizer	7	⇑	
	Human settlements/ Urbanisation (sewage)	Non-point sources	7	⇑	
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Industrialization	Petroleum production	9	⇑	CRP (1999)
	Agriculture	Use of pesticides and fertilizers	7	⇑	
Human health issues	Urbanisation (sewage)	Indiscriminate disposal of human waste	7	⇑	Ibeanu (2000)
Aquatic weeds/ Invasive plants	Transport	Ballast water	8	⇑	AKS (1989)
Loss of habitat/ Biodiversity	All listed drivers	Complex interplay of all factors	7	⇑	NEST (1989) Ibeanu (2000)
Salinisation	?	?	7	⇑	

Table RA 2.4. West Africa: Linking coastal issues/impacts and land-based drivers at the sub-regional scale.

Overview and qualitative ranking on sub-regional scale: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Drivers	West Africa: Related basins	West Africa: Impact Cat.	Trend expectation	References/Data sources
Erosion	Damming	a. Volta b. Senegal	5-9	⇒/⇑	a. Kalitsi (1999) b. Diaw *et al.* (1988, 1990); Barusseau *et al.*(1993); Ba *et al.* (1993); Soumare (1996); Kane (1997)
	Deforestation	a. Volta b. Senegal c. Niger d. Cross	6-8	⇑	a. Tritriku (1999) b. Kane (1997) c. NEST (1989) d. AKS (1989); Okoh and Egbon (1999)
	Agriculture	a. Volta b. Senegal c. Niger d. Cross	7-8	⇑	a. Tritriku (1999) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.* (1993); Soumare (1996); Kane (1997) c. NEST (1989) d. AKS (1989)
	Urbanisation/ human settlement	a. Volta b. Senegal	6	⇑	a. Osei (1969) b. Kane (1997)
	Bush fires	a. Volta b. Senegal	6	⇒	a. Titriku (1999) b. Kane (1997)
	Climate	a. Volta ?	?	?	a. Amissah (1969)
Sedimentation	Agriculture	a. Cross	6	⇑	a. NEST (1989)
	Damming	a. Volta b. Senegal c. Niger	6-9	⇒/I	a. Gordon (1998) b. Diaw *et al.* (1988, 1990); Barusseau *et al.* (1993); Ba *et al.*(1995); Soumare (1996) c. NEST (1989)
Eutrophication	Urbanisation/ Human settlement (Sewage)	a. Volta b. Niger c. Cross	7-10	⇑	a. Osei (1969) b. c. NEST (1989)
	Agriculture	a. Volta b. Niger c. Cross	6-7	⇑	a. Evans (1969) b. c. NEST (1989)
	Bush fires	a. Volta b. Niger	5	⇒	a. Addo-Ashong (1969) b. Finlayson (1998)
	Damming	a. Senegal	4	⇑	a. UNEP (1999)

Table RA 2.4. West Africa, continued.

Coastal Impacts/Issues	Drivers	West Africa		Trend expectation	References/Data sources
		Related basins	Impact Cat.		
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	a. Volta b. Niger c. Cross	7-9	⇑	a. Czernin-Chudenitz (1971) b. NEST (1989); CRP (1999) c. CRP (1999)
	Mining	a. Volta	7	⇑	a. Czernin-Chudenitz (1971)
	Fishing	a. Volta	6	⇓	
	Agriculture	a. Senegal b. Niger c. Cross	7	⇑	a. Titriku (1998) b. NEST (1989); CRP (1999) c. CRP (1999)
	Urbanisation/Human settlement (sewage)	a. Senegal	?	⇑	a. -
Aquatic weeds/ invasive plants	Damming	a. Senegal	9		a. Cogels *et al.* (1993); BDPA-SCETAGRI *et al.* (1995); Matera & Malaisse (1999)
	Active human introduction	a. Volta	7	⇑	a. De Graft-Johnson (1999)
	Urbanisation/human settlement (sewage)	a. Volta	7	⇑	
	Agriculture	a. Volta	7	⇑	
	Bush fires	a. Volta	7	⇒	
	Transport	a. Niger b. Cross	7-8	⇑	a. CRP (1999) b. AKS (1999)
Salinisation	Drought	a. Senegal	5	⇒/⇑	a. Pages *et al.* (1987); Debenay *et al.* (1994); BDPA-SCETAGRI *et al.* (1995); Diouf (1998)
	?	a. Niger	7	⇑	a. Ibeanu (2000)
Human health issues	Urbanisation/human settlement (sewage)	a. Volta b. Senegal c.Niger d.Cross	7-8	⇑	a. Derban (1999) b. Handschumacher *et al.* (1992); Talla (1993); Niang (1999) c. NEST (1989) d. Ibeanu (2000)
	Damming	a. Senegal	8	⇑	a. Handschumacher *et al.* (1992); Talla (1993); Niang (1999)

Table RA 2.4. West Africa, continued.

Coastal Impacts/Issues	Drivers	West Africa		Trend expectation	References/Data sources
		Related basins	Impact Cat.		
Loss of habitat/ biodiversity	Industrialisation	a. Volta b. Niger c. Cross	7-8	⇑	a. Ghana Ministry of Industries (1964) b. Ibeanu (2000) c. Ibeanu (2000)
	Mining	a. Volta b. Niger c. Cross	7-8	⇑	
	Fishing	a. Volta	8	⇑	a. Gordon (1999)
	Agriculture	a. Volta b. Niger c. Cross	7-8	⇑	a. De Graft-Johnson (1999) b. Ibeanu (2000) c. Ibeanu (2000)
	Damming	a. Volta b. Senegal c. Niger	7-8	⇑	
	Active human introduction of weeds	a. Volta b. Niger c. Cross	7-8	⇑	
	Urbanisation/Human settlement (sewage)	a. Volta b. Niger c. Cross	7-8	⇑	
	Deforestation	a. Volta b. Niger c. Cross	7-8	⇑	
	Climate change	a. Volta b. Niger c. Cross	?	⇑	a. Amissah (1969) b. - c. -
	Drought	a. Volta b. Senegal c. Niger d. Cross	7-9	⇑	a. Amissah (1969) b. – c. Ibeanu (2000) d. Ibeanu (2000)
	Transport	a. Niger b. Cross	7	⇑	a. Ibeanu (2000) b. Ibeanu (2000)
	Bush fires	a. Volta	8	⇑	a. Titriku (1999)

Table RA 2.6. West Africa: Scientific and/or management response to coastal impacts/issues.

River catchment	RESPONSE Catchment scale		RESPONSE Sub-Regional (West Africa)	
	Scientific	**Management**	**Scientific**	**Management**
Volta	Ghana water resources management study (1998) Lower Volta environmental impact study (VBRP, 1996-2001) Ghana coastal wetland management project (1992-1997) GEF Integrated coastal zone management strategy for Ghana (World Bank, 1996)	Ghana water resources management study (1998) Lower Volta environmental impact study (VBRP, 1996-2001) Ghana coastal wetland management project (1992-1997) GEF Integrated coastal zone management strategy for Ghana (World Bank, 1996)	Large marine ecosystem Gulf of Guinea Project (1995-2001) UNIDO-GEF Transboundary diagnostic analysis for the Volta Basin UNEP-GEF (ongoing) Mahe (1993) – study referring to all basins discharging to the Atlantic Ocean	Large marine ecosystem Gulf of Guinea Project (1995-2001) UNIDO-GEF Transboundary diagnostic analysis for the Volta Basin UNEP-GEF (ongoing)
Senegal	Michel *et al.* (1993) L'Apres Barrage dans la vallee du Senegal EQUESEN (1993) Environnement et Qualite des Eaux du fleuve Senegal SEAH (1996) Transformation des Hydrosystemes lies aux grands barrages en Afrique soudanienne et sahelienne BDPA (1996) Bilan Diagnostic du Delta du Senegal	OMVS (Organisation pour la mise en valeur du fleuve Senegal) Initiatives to combat the invasion by macrophytes; others to combat inundations Danish Project for the elaboration of an integrated management of the delta		

Table RA 2.6. West Africa, continued.

River catchment	RESPONSE Catchment scale		RESPONSE Sub-regional (West Africa)	
Niger	Environmental Diagnostic Studies (NDES 1997) Niger Delta Development Cooperation (NDDC 2001)	Environmental Diagnostic Studies (NDES 1997) Niger Delta Development Cooperation (NDDC 2001) Federal Environmental Protection Agency (FEPA) Federal Ministry for Environment		
Cross	Control of pollution, flood in the Cross river Basin (CRBDA 1976) Environmental Inventory survey (AKS 1989)	Federal Environmental Protection Agency (FEPA) Control of pollution, flood in the Cross river basin (CRBDA 1976) State Minister of the Environment (AKS 1989)		

Republique du Senegal/SGPRE; DHI , PNUE , (2001): Gestion integree du littoral et des bassins fluviaux (GILIF/IRCAM): programme pilote du delta du fleuve Senegal.

GEF/Programme (1999-2004) : Biological diversity conservation. Through participatory rehabilitation of the degraded land of the semi-arid and transboundary areas of Senegal and Mauritania. UNDP/UNEP/GEF 1999-2004.

Republique du Senegal/ Ministere de la Jeunesse de l'Evironnement et de l'Hygiene Publique /SP//CONSERE/Unite de Coordination du projet (UCP) (2001): Projet de gestion de la biodiversite marine et cotiere. GEF/ Don TF Q24759 /Banque mondiale.

Table RA 2.7. West Africa: Hot spots of land-based coastal impact, gaps in understanding and an overview of issues to be addressed in future research.

River catchment	Hot spot catchment scale		Hot spot West Africa sub-region		Hot spot Regional scale	
	Key issues, trend and gaps	**Scientific approach**	**Key issue, Trend and gaps**	**Scientific approach**	**Key issue, Trend and gaps**	**Scientific approach**
Volta	Erosion	Measurement of slopes, run-off speed and sediment loads	Erosion	Measurement of slopes, speed of runoff and sediment loads	Erosion	Measurement of slopes, speed of runoff and sediment loads
	Sedimentation	Measurements of sediment loads	Sedimentation	Measurements of sediment loads	Sedimentation	Measurements of sediment loads
	Pollution Pesticides	Monitoring water quality parameters in the Volta Lake/use of questionnaires	Pollution Pesticides	Monitoring water quality parameters/use of questionnaires	Pollution Pesticides	Monitoring water quality parameters/use of questionnaires
	Aquatic weeds including invasive plant species	Assessment of species population	Aquatic weeds including invasive plant species	Assessment of species population	Aquatic weeds including invasive plant species	Assessment of species population
	Loss of habitat/ Biodiversity	Assessment of river biodiversity	Loss of habitat/ biodiversity	Assessment of river biodiversity	Loss of habitat/ biodiversity	Assessment of river biodiversity
	Human Health issues	Socio-economic studies/ questionnaire administration	Human health issues	Socio-economic studies/ questionnaire administration	Human health issues	Socio-economic studies/ questionnaire administration
Senegal	Coastal changes	Use of aerial photographs and satellite images Monitoring of the Langue de Barbarie sand spit				
	Sediment and chemical fluxes	Field work with sampling sites				
	Control of pollutants (pesticides and fertilizers)	Sampling and analysis of water samples				
	Inundation control	Monitoring of the technical structures (sand bags mainly) and their efficiency				

Table RA 2.7. West Africa, continued.

River catchment	Hot spot catchment scale		Hot spot West Africa sub-region		Hot spot Regional scale	
Niger	Water pollution	Studies of water quality				
	Invasion by exotic weeds (nypa palm and water hyacinth)	Assessment of the impact of nypa palm and water hyacinth on aquatic population and rural livelihood				
	Oil spillage	Assessment of impact of oil spillage on the environment				
	Silting	The study of extent an impact of silting on the coastal environment				
	Health problems	Study of the impact of environmental pollution on human health				
Cross	Beach erosion	Study of the extent an impact of beach erosion on coastal environment				
	Nypa palm invasion	Assessment of impact on the biodiversity				
	Oil pollution	Assessment of extent and effect of oil pollution on environment and people's livelihood				
		Study of biodiversity loss				
	Biodiversity loss	Geological studies of coastal and oil producing community				
	Earth tremors					

Regional Assessment Tables 3. Congo *by P. Morant and Susan Taljaard*

Table RA 3.1. Congo: Major coastal impacts/issues and critical thresholds.

*Overview and qualitative ranking: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category*	References/ Data source
Loss of habitat/Biodiversity	Congo	Not known	?	7	UNEP (1999); Morant (2001); Morant pers. comm.
Pollution – hydrocarbons & heavy metals	Congo	Not known	?	3	

Table RA 3.2. Congo: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact *versus* catchment size class

P = progressive, **D** = distinct

Driver	Pressures	State change Qualitative index	Impact on the coastal system	Time scale
		Large basin> 200,000 km^2		
Deforestation	Loss of coastal habitat (mangroves)	**major**	Habitat/biodiversity loss	**P**
Industrialisation	Modification of water quality (oil)	**minor**	Pollution Habitat/biodiversity loss	**P**
Human settlements/urbanisation	Loss of coastal habitat	**minor**	Habitat/biodiversity loss	**P**

Tables RA 3.3 & 3.4. Congo: Linking coastal issues/impacts and land-based drivers at the catchment and sub-regional scales.

Overview and qualitative ranking on sub-regional scale, 1 = minimum, 10 = maximum

Coastal Impact/Issues	Drivers	Motivation	Impact Category	Trend expectations	References/ Data sources
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	Ship traffic and associated oil pollution (although not expected to be that severe)	3	?	
Loss of habitat/ biodiversity	Deforestation	Almost 40% of the total mangrove surface area near the mouth may have been lost through extensive fuel wood cutting (production of charcoal)	7	⇑	UNEP (1999); Morant (2001)
	Human settlements/ Urbanisation	Uncontrolled development (human settlements) is listed as one of the threats to the RAMSAR status of the Parc National des Mangroves	3	⇑	Morant (2001)
	Industrialisation	Ship traffic and associated oil pollution	3	⇑	Morant (2001); Morant, pers. comm

Table RA 3.6. Congo: Scientific and/or Management RESPONSE to coastal impact/issues

River catchment	RESPONSE	
	Scientific	Management
Congo	?	Provision of technical support to the Democratic Republic of the Congo through the Ministry of the Environment and Tourism has been given to allow it to prevent and/or reduce the pollution and degradation of the coastal environment caused by land-based activities (UNEP 1999).

Regional Assessment Tables 4. South West Africa *by Susan Taljaard*

Table RA 4.1. South West Africa: Major coastal impacts/issues and critical thresholds.

*Overview and qualitative ranking: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category*	References/ Data source
Sedimentation	a. Gariep b. Olifants c. Berg River	a. Not known b. Not known c. Not known	a. Not exceeded, but could be near threshold (disturbance of sedimentation process in the mouth area) b. Not exceeded c. Not exceeded	a. 4 b. 3 c. 3	a. DWAF (1989); DWAF (1993) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
Eutrophication (e.g. algal blooms)	a. Saldanha Bay	a. Occurrence of excessive algal growth (e.g. *Aureococcus* sp. and *Ulva*)	a. Occasionally passes critical threshold in the mid-late summer, particularly in more stratified and depositional areas of the bay (more than would have occurred naturally)		a. Monteiro & Largier (1999); Monteiro *et al.* (1999)
Aquatic weeds/invasive plants	a. Table Bay b. False Bay	a. Occurrence of nuisance reed beds b. Occurrence of nuisance reed beds	a. Exceeded in some estuaries due to nuisance reed growth b. Exceeded in some estuaries due to nuisance reed growth		a. Quick & Roberts (1993) b. Taljaard *et al.* (2000)
Pollution, e.g. Hydrocarbons (1) Heavy metals (2) Pesticides (3)	a. Gariep (3) b. Olifants (3) c. Berg (3) d. Saldanha Bay (1,2) e. Table Bay (1,2) f. False Bay (1,2)	a-c. Generic critical thresholds can be derived from literature, but currently site specific values are not available d-f. For harbours, critical thresholds have been recommended for trace metals (under the London Convention, 1973).	a. Not exceeded b. Not exceeded c. Not exceeded d-f. Localised areas in harbours are close to or exceeding critical limits	a. 2 b. 2 c. 2 d. 4 e. 4	a. DWAF (1993) b. Taljaard (1997) c. DWAF (1994) d. Monteiro & Largier (1999); Monteiro *et al.* (1999) e. Quick & Roberts (1993); Monteiro (1997) f. Taljaard *et al.* (2000)

Table RA 4.1. South West Africa, continued.

Coastal Impacts/Issues	Local site/Region	Critical Threshold	Distance to Critical Threshold	Impact category*	References/ Data source
Salinisation (e.g. associated with reduction in freshwater inflows)	a. Gariep b. Olifants c. Berg	a. Not known b. Not known c. Not known	a. Not exceeded b. Not exceeded c. Not exceeded	a. 3 b. 3	a. DWAF (1989) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
Loss of habitat/ biodiversity	a. Gariep b. Olifants c. Berg d. Saldanha Bay e. Table Bay f. False Bay	a. Not known b. Not known c. Not known d. Not known e. Not known f. Not known	a. Probably exceeded or near through large salt marsh areas being cut off from river by the coastal road b. Not exceeded c. Not exceeded d. Exceeded in localized areas, e.g. harbour area e. Exceeded in localized areas, e.g., estuaries f. Exceeded in localized areas, e.g. estuaries	a. 6 b. 3 c. 3 d. 6 e. 6 f. 6	a. DWAF (1993) b. Huizinga & Van Niekerk (1997); Taljaard (1997) c. DWAF (1994) d. Monteiro & Largier (1999); Monteiro *et al.* (1999) e. Quick & Roberts (1993) f. Taljaard *et al.* (2000)
Human health issues	a. False Bay b. Table Bay	a-b. *E. coli* counts not to exceed 100 counts/100 ml for 80% of the time and 2000 counts/100 ml for 95% of the time	a-b. Thresholds exceeded in localized areas (within 500 m of river mouths and storm water discharges).	a. 4 b. 4	a. CMC (1999) b. Taljaard *et al.* (2000)

Table RA 4.2. South West Africa: DPSI matrix characterising major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact *versus* catchment size class.

NOTE: Human settlement/Urbanisation, Industrialisation, Mining and Deforestation are not key drivers associated with coastal impacts from the river basins in south-western Africa. Some of these drivers (particularly human settlement/urbanisation and industrialisation), however, are key drivers of coastal impacts in the urban nodes along this stretch of coast, e.g., Saldanha Bay, Table Bay (Cape Town) and False Bay (Cape Town).

P = progressive, **D** = discrete

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km² (Gariep)	Medium basins 10 000 – 200 000 km² (Olifants)	Small basins < 10 000 km² (Berg)		
Damming	Modification of hydrological regime (runoff)	**medium**	**medium**	**medium**	Sedimentation Habitat/biodiversity loss	**P**
	Modification of water quality (e.g. salinity regime)	**medium**	**medium**	**medium**	Habitat/biodiversity loss	**P**
	Modification of morphological regime (sedimentation/erosion)	**medium**	**medium**	**medium**	Sedimentation Habitat/biodiversity loss	**P**
Agriculture	Modification of hydrological regime (runoff)	**minor**	**minor**	**minor**	Sedimentation Habitat/biodiversity loss	**P**
	Modification of water quality	**minor**	**minor**	**minor**	Aquatic weeds Pollution Habitat/biodiversity loss	**P**
	Modification of morphological regime (sedimentation/erosion)	**minor**	**minor**	**minor**	Sedimentation Habitat/biodiversity loss	**P**
Transport	Modification of coastal habitat	**medium**	**minor**	**minor**	Habitat/biodiversity loss	
Climate change	Modification of hydrological regime (runoff)	**?**	**?**	**?**	Sedimentation Biodiversity loss	**P**
	Sea level rise	**?**	**?**	**?**	Erosion Salinisation	**P**

Table RA 4.3. South West Africa: Linking coastal issues/impacts and land-based drivers.

Overview and qualitative ranking on catchment scale: 1 = minimum, 10 = maximum

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Gariep catchment			
Loss of Habitat/ biodiversity	Damming	Reduced river inflow resulted in changes in habitat characteristics, e.g. changes in the salinity regime and characteristics of the substratum	6	⇑	DWAF (1989, 1993)
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow	4	⇑	
	Transport	Coastal road cut off flood plain from river, thus damaging the flood plain vegetation (salt marsh)			DWAF (1989)
Sedimentation	Damming	Alterations in river flow regime has altered the sedimentation processes in estuaries, altering the duration and timing of mouth closure/opening	6	⇑	DWAF (1989, 1993)
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow (see above)	4	⇑	
Salinisation	Damming	During low flow periods saline intrusion from the sea or as a result of high evaporation may affect the quality of ground water resource	4	⇑	DWAF (1989)
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow (see above)	4	⇑	DWAF (1989, 1993)
	Climate change	Sea level rise may increase upstream saline intrusion	?	?	-
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Catchment supports major agricultural activities probably introducing some pesticides to coastal areas.	2?	⇑	-

Table RA 4.3. South West Africa, continued.

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Olifants catchment			
Loss of habitat/ biodiversity	Damming	Reduced river inflow resulted in changes in habitat characteristics, e.g. changes in the salinity regime and characteristics of the substratum	4	⇑	Huizinga & Van Niekerk (1997)
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow	3	⇑	
Sedimentation	Damming	Reduced river flows allow marine sediments to accumulate in estuaries and altered the duration and timing of mouth closure/opening	4	⇑	
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow	3	⇑	
Salinisation	Damming	Reduced river inflow results in increased saline intrusion upstream	4	⇑	
	Agriculture	Water abstraction for irrigation also reduces the freshwater inflow	3	⇑	
	Climate change	Sea level rise may increase upstream saline intrusion	?	?	-
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Catchment supports major agricultural activities probably introducing pesticides to the coastal zone.	2?	⇑	Taljaard (1997)
		Berg catchment			
Loss of habitat/ biodiversity	Damming	Reduced river inflow resulted in changes in habitat characteristics, e.g. changes in the salinity regime, characteristics of the substratum and mouth dynamics.	4	⇑	DWAF (1994)
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow (as above)	3	⇑	
Sedimentation	Damming	Reduced river flows allow marine sediments to accumulate in estuaries and altered the duration and timing of mouth closure/opening	4	⇑	
	Agriculture	Water abstraction for irrigation also alters the freshwater inflow (as above)	3	⇑	

Table RA 4.3. South West Africa, continued.

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Berg catchment continued			
Salinisation	Damming	Reduced river inflow results in increased saline intrusion upstream	4	⇑	
	Agriculture	Water abstraction for irrigation reduces the freshwater inflow (as above)	3	⇑	
	Climate change	Sea level rise may increase upstream saline intrusion	?	?	-
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Catchment supports major agricultural activities probably introducing pesticides to the coastal zone.	2	⇑	DWAF (1994); Slinger & Taljaard (1994)
		Saldanha Bay			
Loss of Habitat/ Biodiversity	Urbanisation	Physical loss of habitat due to development in the coastal zone	3	⇑	Monteiro & Largier (1999); Monteiro *et al.* (1999)
	Industrialisation	Physical loss of habitat due to development in the coastal zone	3	⇑	
Eutrophication	Industrialisation	Increase in concentrations of nutrients due mainly to fish factory effluents	6	⇑	
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Industrialisation	Industries associated with the harbour contributes to toxic pollutant loads (e.g. trace metals and hydrocarbons)	4	⇑	
	Urbanisation	Storm water runoff from built-up urban areas contributes to localized toxic pollutant loads (e.g. trace metals and hydrocarbons)	4	⇑	
Human health issues	Industrialisation	Increase in human pathogens due mainly to fish factory effluents	4	⇑	
Erosion	Climate change	Sea level rise may result in coastal erosion	?	?	-

Table RA 4.3. South West Africa, continued.

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Table Bay (Cape Town)			
Loss of habitat/ biodiversity	Urbanisation	Physical loss of habitat due to urban development in the coastal zone. Alteration in the flow regime (increase in runoff due to increase in built-up areas) alters the habitat, e.g., salinity regime	4	⇑	Quick & Roberts (1993)
Sedimentation	Urbanisation	Poor catchment management results in soil erosion upstream and sedimentation in coastal areas (e.g., estuaries)	3	⇑	
Aquatic weeds/ invasive plants	Urbanisation (sewage)	Increase in concentrations of nutrients due to sewage point source and non-point source disposal results in excessive reed growth in some estuaries along the bay	4	⇑	
	Agriculture	Use of fertilizer in the catchment results in excessive reed growth in some estuaries along the bay	4	⇑	
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	Industries and activities associated with the harbour contributes to localized toxic pollutant loads (e.g. trace metals and hydrocarbons)	4	⇑	Quick & Roberts (1993); Monteiro (1997)
	Urbanisation	Storm water runoff from built-up urban areas contributes to localized toxic pollutant loads (e.g. trace metals and hydrocarbons)	4	⇑	
Human health issues	Urbanisation	Increase in human pathogens due contaminated storm water runoff in localized areas along the coast	4	⇑	Quick & Roberts (1993)
Erosion	Climate change	Sea-level rise may result in coastal erosion	?	?	-

Table RA 4.3. South West Africa, continued.

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/data sources
		False Bay (Cape Town)			
Loss of Habitat/ Biodiversity	Urbanisation	Physical loss of habitat due to urban development in the coastal zone Alteration in the flow regime (increase in runoff due to increase in built-up areas) alters the habitat, e.g., salinity regime	4	⇑	Taljaard *et al.* (2000)
Sedimentation	Urbanisation	Poor catchment management results in soil erosion upstream and sedimentation in coastal areas (e.g., estuaries)	3	⇑	
	Agriculture		3	⇑	
Aquatic weeds/invasive plants	Urbanisation (sewage)	Increase in concentrations of nutrients due to sewage point source and non-point source disposal results in excessive reed growth in some estuaries along the bay	4	⇑	
	Agriculture	Use of fertilizer in the catchment results in excessive reed growth in some estuaries along the bay	4	⇑	
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	Industries and activities associated with the harbour contributes to localised toxic pollutant loads (e.g. trace metals and hydrocarbons)	4	⇑	
Human health issues	Urbanisation	Increase in human pathogens due contaminated storm water runoff to the coastal zone	4	⇑	
Erosion	Climate change	Sea-level rise may result in coastal erosion	?	?	-

Table RA 4.4. South West Africa: Linking coastal issues/impacts and land-based drivers at the sub-regional scale.

Overview and qualitative ranking on sub-regional: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Drivers	South-western Africa		Trend expectation	References/data sources
		Related basins	Impact Category		
Erosion	Climate change	a. Saldanha Bay b. Table Bay c. False Bay	?	?	-
Sedimentation	Damming	a. Gariep b. Olifants c. Berg	4-6	⇑	a. DWAF (1989, 1993) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
	Agriculture	a. Gariep b. Olifants c. Berg	3	⇑	
Salinisation	Damming	a. Berg b. Olifants	4	⇑	a. Huizinga & Van Niekerk (1997) b. DWAF (1994)
	Agriculture	a. Berg b. Olifants	3	⇑	
	Climate change	a. Gariep b. Olifants c. Berg	?	?	-
Eutrophication	Industrialisation	a. Saldanha Bay	6	⇑	a. Monteiro & Largier (1999); Monteiro *et al.* (1999)
Pollution (e.g., trace metals, hydrocarbons, pesticides)	Industrialisation	a. Saldanha Bay b. Table Bay c. False Bay	4	⇑	a. Monteiro & Largier (1999); Monteiro *et al.* (1999) b. Quick & Roberts (1993) c. Taljaard *et al.* (2000)
	Urbanisation/Human settlements	a. Table Bay b. False Bay	4	⇑	a. Quick & Roberts (1993) b. Taljaard *et al.* (2000)

Table RA 4.4. South West Africa, continued.

Coastal Impacts/Issues	Drivers	South western Africa		Trend expectation	References/Data sources
		Related Basins	Impact Category		
Aquatic weeds/ invasive plants	Urbanisation/Human settlements	a. Table Bay b. False Bay	4	⇑	
	Agriculture	a. Table Bay b. False Bay	4	⇑	
Human health issues	Urbanisation	a. Table Bay b. False Bay	4	⇑	
	Industrialisation	a. Saldanha Bay	4	⇑	a. Monteiro & Largier (1999); Monteiro *et al.* (1999)
Loss of habitat/ biodiversity	Damming	a. Gariep b. Olifants c. Berg	4-6	⇑	a. DWAF (1989, 1993) b. Huizinga & Van Niekerk (1997) c. DWAF (1994)
	Agriculture	a. Gariep b. Olifants c. Berg	3	⇑	
	Human settlements/ Urbanisation	a. Table Bay b. False Bay	4	⇑	a. Quick & Roberts (1993) b. Taljaard *et al.* (2000)
	Industrialisation	a. Saldanha Bay b. Table Bay c. False Bay	4	⇑	a. Monteiro & Largier (1999); Monteiro *et al.* (1999) b. Quick & Roberts (1993) c. Taljaard *et al.* (2000)
	Transport	a. Gariep	6	⇒	a. DWAF (1989)
	Climate change	a. Gariep b. Olifants c. Berg d. Saldanha Bay e. Table Bay f. False Bay	?	?	-

Table RA 4.6. South West Africa: Scientific and/or management response to coastal impact/issues.

River catchment	RESPONSE Catchment scale		RESPONSE Sub-regional (South Africa)	
	Scientific	Management	Scientific	Management
Gariep	-	-	-	The National Water Act of South Africa (Act 36 of 1998) states that the natural environment has a right to water. As a result, the quantity and quality of water and other resource quality objective need to be determined for river catchments. The national Department of Water Affairs and Forestry are responsible for setting the 'Reserve and Resource Quality Objectives' for catchments, including estuaries. To facilitate implementation of these measures, the law requires that Catchment Management Agency (CMA) and Catchment Management Forums be put in place for each basin.
Olifants	-	-		
Berg	CSIR's catchment-to-coast initiative in this area	Department of Water Affairs and Forestry to initiate a monitoring programme in the area		
Saldanha Bay	Joint CSIR – Marine and Coastal Management (Department of Environmental Affairs) Project (Monteiro & Largier, 1999)			
Table Bay	-	-		
False Bay	Review on anthropogenic inputs undertaken in 2000 (Taljaard *et al.*, 2000)	-		

Table 4.7. South West Africa: Hot spots of land-based coastal impact, gaps in understanding and an overview of issues to be addressed in future research.

Although there are some potential hotspots in this sub-region, these are not as serious as those identified, for example along the other parts of West Africa. If one needs to ID hotspots in this region, it would probably be the two basins Gariep (Priority 2) and Berg (Priority 1), while Saldhana Bay is probably the 'hottest spot' of the 3 coastal nodes.

River catchment	Hot spot Catchment scale	
	Key issue, trend and gaps	Scientific approach
Gariep	• Impacts of altered freshwater inflow (and possibly also reduced sediment input), as a result of damming and agricultural use, on the coast (as well as associated industries such as diamond mining and fishing) has not been established	Monitoring required to determine the extent and severity of current impacts on the coast and to establish linkages with catchment-derived drivers Predictive capabilities currently applied in other southern African catchments be implemented and adapted for the Gariep to provide scientific support underpinning effective management
Berg	• Changes occurred in the hydrological regime (reduction in inflow) and geomorphology due to upstream damming • Further damming is under consideration • Additional data are required to predict the extent, severity and implication of damming with greater confidence	The Department of Water Affairs and Forestry is in the process of initiating an extensive monitoring programme. The CSIR is developing numerical tools (through the catchment-to-coast initiative) to provide sound scientific predictive capabilities essential for effective management of coastal issues
Saldanha Bay	• Increasing urbanisation and industrialization results in impacts, such eutrophication and pollution. • Extensive research studies has already provided valuable scientific understanding, but these need to be transformed into effective, practical management plans to address issues.	The Saldanha Bay Water Quality Forum has been established to coordinate management efforts towards addressing key issues The CSIR has set up sophisticated hydrodynamic and water quality numerical models so as to provide sound scientific predictive capabilities essential for effective management of the area

Regional Assessment Tables 5. Nile sub-region *by Hassan Awad*

Table RA 5.1. Nile - Major coastal impacts/issues and critical thresholds

*Overview and qualitative ranking: Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Erosion	a. Rosetta promontory b. Burullus Lake area c. Damietta promontory	a. Current erosion rate 53-102 m/yr b. Erosion rate: 5.5 m/yr c. Erosion rate: 10.4 m/yr	a. Aswan Dam (1968) prevented sediment discharge (160 Mt/yr) into Mediterranean.	9	a. Hydraulic Resource Analysis (1992); Frihy & Lotfy (1994); Frihy *et al.* (1994) b. Frihy & Dowidar (1993) c. Frihy & Komar (1993)
Sedimentation	All Mediterranean coastal lagoons	Area reduced from 960,000 to 260,000 hectares in last 40 years	Uncontrolled land reclamation; urbanisation	8	Hanafy(1998)
Eutrophication	Abu Qir Bay, adjacent to Nile Delta	High nutrient loads, especially P through agricultural drainage and sewage NH_4 – 6-14.2 μg/l NO_3 – 5.7-19 μg/l PO_4 – 1-4 μg/l O_2 - <4 mg/l Chl.a : 15-48 μg/l	Redfield ratio is broken C: N:P 82:5.5:1	6	Abdel Aziz & Dorgham (1999); Abdel Aziz *et al.* (2001); El Rayis *et al.* (1994)
	Alexandria City Coast	Nearshore waters receive $200x10^3m^3$ of untreated domestic sewage from two outfalls. Around these sites nutrients are normally found in high concentration: NH_4 – 14.5-38.7 μg/l NO_3 – 5.7-19 μg/l PO_4 – 1-6 μg/l O_2 - <4 mg/l Chl.a : 34-107 μg/l	Redfield ratio is broken C:N:P 218:4:1	5	Zaghloul & Halim (1992); Dorgham *et al.* (2001)

Table RA 5.1. Nile, continued.

Coastal IMPACT/ ISSUE	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Pollution	Mex Bay (River Nile)	Receives 2 bm^3/yr mixed wastewater loaded with $220x10^3$ t/yr BOD; 75x10 t/yr COD; $2x10^3$ t/yr TN; $2.6x10^3$ t/yr TP & $287x10^3$/yr TSS. Standing stocks: 840 t/yr TN; 30 t/yr TP & 3000 t/yr TSM. The Bay environment also receives $75x10^3$ t/yr toxic metals (Hg, Cd, Cr, Cu, Zn & Ni) and 1300 t/yr of Oil.	Hot spot in the Mediterranean; alteration in biodiversity; eutrophication; high levels of toxic heavy metals and PAH are frequently detected in marine fauna and flora; negative impact on fisheries and fish speciation.	9	UNEP (1990); Younes *et al.* (1997); UNEP/WHO (1999)
	Alexandria City Coast	Receives 145 Mm^3 /yr domestic wastes loaded with $1.5x10^3$ TN; $2.3x10^3$ t/yr TP & $8.8x10^3$ t/yr TTS & 540 t/yr Oil wastes from refineries	Hot spot in the Mediterranean. Health hazards from near shore untreated discharge of sewage. Eutrophication and Red Tide. Negative impact on fisheries and on submerged archaeological heritage.	5	Atta(1985); UNEP(1990); Awad (1995); UNEP/WHO (1999)
	Abu Qir Bay (River Nile)	Receives 410 Mm^3/yr mixed wastewater With $90x10^3$ t/yr BOD; $575x10^3$ t/yr COD; $5x10^3$ t/yr TN; $8.5x10^3$ t/yr TP and $120x10^3$ TSS.	Hot spot in the Mediterranean. The Bay's environment suffers from high load of industrial wastes and untreated sewage discharge especially black liquor and fertilizer industry wastes	9	El Deeb (1977); UNEP(1990); UNEP/WHO (1999); Younes *et al.* (1997); Awad & Yousef (2001)
	Edku Lake (River Nile)	Agriculture drains receive about 1bm^3/yr drain water. Discharge 400 Mm^3/yr of brackish water into Abu Qir Bay loaded with 12 t/yr NO_2, 8 t/yr NO_3 and 9 t/yr PO_4. π = 20-60 d, p-r = 3.2 mmol/m^2/d in summer and 1.3 mmol/m^2/d in winter; nfix-denit=1.6 mmol/m^2/d in summer and 22.7 mmol/m^2/d in winter	Nitrogen fixing system frequently its discharged water quality cause eutrophication in the Abu Qir Bay receiving environment	5	Saad (1997); Awad & Hassan (1998); Awad & Yousef (2001)

Table RA 5.1. Nile, continued.

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
	Burullus Lake (River Nile)	Discharge into Mediterranean 2.2 bm^3/yr brackish water loaded with insignificant N & P; (0.03 t/yr NO_2; 0.2 t/yr NO_3 and 0.01 t/yr PO_4	Clean coastal lagoon considered as natural reserve	0	Saad (1997); Awad & Hassan (1998)
	Manzalla Lake (River Nile)	Receives 1.7 bm^3/yr of partially or untreated wastes, discharges 7 bm^3/yr into the Mediterranean loaded with 40 t/yr NO_2; 156 t/yr NO_3 and 71 t/yr PO_4	Hot spot in the Mediterranean	9	EEAA (1992); Awad & Hassan (1998)
	Damietta Nile Estuary	Stop discharging freshwater into the Mediterranean following the construction of the El Salam Canal transporting Nile water to Sinai (3.3 bm^3/yr) for irrigation		2	
	Bardawil Lake	Sensitive area, hypersaline lagoon, no discharge and free of pollution	Overfishing area (fish catch decreased in 1992 by 40% relative to that of 1970). Biodiversity under threat following the arrival of Nile waters through the El Salam Canal and agriculture activity around the lake with increasing settlement. Impacts on groundwater quality and coastal erosion are predicted.	0	UNEP/WHO (1999)
Salinisation					EEAA (1992)

Table RA 5.2. Nile: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact versus catchment size class.

P= progressive, **D** = discrete

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km²	Medium basins 10 000 – 200 000 km²	Small basins: > 10 000 km²		
Damming	Changing hydrology	**major**	-	-	Coastal erosion, land loss Severe reduction in sediment discharge Nutrient supply loss Salinisation	**P**
Agriculture	Increased nutrient and pesticide fluxes	**major**	-	-	Eutrophication Degradation of groundwater quality	**P**
Urbanisation and Industrialisation	Sewage production Industrial waste production Deterioration in water quality	**major**	-	-	Pollution Eutrophication Health hazards Biodiversity Fisheries Recreation	**P**

Tables RA 5.3 & 5.4. Nile: Linking coastal issues/impacts and land-based drivers at the catchment and sub-regional scales

Overview and qualitative ranking on sub-regional scale: Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impact/Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		River Nile	**Impact Category**		
Erosion	Damming Climate change	Mouths of Rosetta and Damietta distributaries Possible contributor to coastal erosion	8 8	⇑ ⇑	Sestini (1992); Frihy & Komar (1993); Stanley (1996)
Eutrophication	Agriculture Urbanisation Industrialisation	High consumption of fertilizers Uncontrolled coastal urbanisation without sewage treatment facilities High loaded wastes with organics	? ? ?	? ? ⇒	Awad (1994) EEAA (1996) Awad (1994)
Pollution	Damming Agriculture Urbanisation Industrialisation	Around Hot Spots Around Hot Spots Around Hot Spots	7 7 7	⇓ ⇒ ⇒	EEAA (1996) EEAA (1992)
Biodiversity loss	Damming Agriculture Urbanisation Industrialisation	Usage of high quantities of pesticides Landfilling of coastal lagoons Hazardous wastes discharge	 ? 8 ?	? ⇑ ⇒	Hanafy (1998) Awad (1994)
Human health issues	Damming Agriculture Urbanisation Industrialisation	Pesticides usage Discharge of untreated domestic/industrial wastes in coastal lagoons and the river Atmospheric precipitation in industrial zones around coastal lagoons	? 8 8	⇓ ⇓ ⇒	 Awad (1994) Abo Zahra (2000) EEAA (1992, 1996)

Table RA 5.6. Nile: Scientific and/or management response to coastal impact/issues in African coastal zones on catchment, sub-regional and regional scales

River catchment	RESPONSE Catchment scale		RESPONSE Sub-regional/ Country scale		RESPONSE Regional scale	
Nile	Scientific	Management	Scientific	Management	Scientific	Management
	Nile water quality monitoring. Coastal water quality monitoring. Pollution impact assessment on Nile and marine resources. Pollution hot spot monitoring. Sea level rise monitoring.	Legislation and enforcement measures since 1994. Creation of EEAA. (Egyptian Environmental Affairs Agency) and its 8 Regional Branches. National CZM plan and committee. Implementation of national programmes for: -Nile water monitoring -Shoreline protection and planning -GIS data base -Domestic/industrial waste treatment	MedPol programmes MedGOOS monitoring Environmental Information Monitoring Programme	MAP/UNEP MAMA/IOC EIMP/DANIDA	MedPol programmes MedGOOS monitoring	MAP/UNEP MAMA/IOC

Table RA 5.7. Nile: Hot spots of land-based coastal impact and gaps in understanding as well as a first overview of issues to be addressed in future research.

River catchment	Hot spot Catchment scale		Hot spot Sub-regional/ Country scale		Hot spot Regional scale	
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
Nile	• River water quality • Loss of fisheries • Pollution • Erosion • Land-filling	• Biogeochemical studies especially in coastal lagoons • Modeling of hazardous substances dispersion in coastal waters • Assessment of pollution receiving water assimilation capacity • River, lagoons and coastal living resource management • Biodiversity • Shoreline protection/planning management • Pollution control management • Stakeholders awareness				

Regional Assessment Tables 6. East Africa *by J. Kitheka, J. Ochiewo and A. Ngusaru*

Table RA 6.1. East Africa: Major coastal impacts/issues and critical thresholds.
Many of the reported coastal issues in this sub-region are linked not to activities within catchments, but rather to land-based activities at the coast itself, notably related to the major urban nodes of Dar es Salaam and Mombasa, and coastal tourism development.

*Overview and qualitative ranking on catchment scale. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal IMPACT/ ISSUE	Local site/Region (contributing river basins)	Critical Threshold (for system functioning)	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Erosion	a. Tana delta b. North Kenya coast (Shanzu, Kanamai), South Kenya coast (Diani, Likoni); contributing rivers unknown c. Bagamoyo and Dar es Salaam (Ruvu river) d.Rufiji e. Mtwara-Lindi stretch (Mbemkuru and Ruvuma rivers) f. Kilwa (Rufiji river) g. Jambiani, Paje, Maruhubi, Nungwi areas in Zanzibar	a. Not known b. Not known c-g. Not known	a. Not known b. Critical load already passed c. Critical load already passed for Bagamoyo and Dar es Salaam (4m retreat per year) d-f. Erosion considered to be occurring, rate unknown g. Critical load passed for Jambiani, retreat estimate unknown	8 8	a. Raal & Barwell (1995); Knocker (1998) b. Okemwa *et al.* (1994) c-g. Mushala (1978); Ross and Saint-Ange (1986); Fay (1987, 1992), Griffiths (1987); Lwiza & Bigendako (1988); Arthurton (1992); Shaghude *et al.* (1994); Arthurton *et al.* (1999); TCMP (2000, 2001); Ngusaru *et al.* (2001); UNEP (2001)
Sedimentation (e.g. marine sedimentation due to reduced freshwater inflow or from agricultural practices)	a. Tana delta and Ungwana Bay b. Sabaki mouth and Malindi Bay c. Port Reitz/Mwache creek d. Rufiji e. Ruvuma	a.b. Unknown but could be about 5% of annual load. Silting of Malindi Bay. Smothering of coral in Malindi Marine Park. d. Smothering of seagrass beds and coral near Rufiji delta and the south of Mafia Island, siltation as far as Mkuranga.	a. Critical load already passed. Tana sediment load 1-8 mt/yr b. Sabaki sediment discharge 2 mt/yr d. Critical load passed e. Unknown	8	a-b. Gibb (1959); ILACO (1971); Dunne (1975); Dunne & Ongwenyi (1976), Edwards (1979); UNEP (1998); Otieno & Maingi (2000). c. Kitheka (2000) d. Francis (1992); Fisher *et al.* (1994); Ngusaru *et al.* (2001)

Table RA 6.1. East Africa, continued.

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning)	Distance to Critical Threshold (qualitative or quantitative)	Impact category*	References/ Data source
Eutrophication	a.Tana b.Sabaki	a,b. DO level > 5mg/l and TSSC >0.05 g/l	C:N:P ratio not known	4	a. Kitheka (2000)
Pollution Sewage, industrial and shipping discharge	a.Mtwapa creek b.Makupa creek c.Kilindini channel d. Rufiji and Ruvuma			5-8	a.-c. Rees *et al.* (1996); Kitheka (2000). d. TCMP (2000, 2001); Ngusaru *et al.* (2001)
Biodiveristy loss (loss of biological function)	a.Ungwana Bay-Tana b.Funzi Bay c.Bamburi-Nyali lagoon d.Diani-Gazi lagoon e. Rufiji-Kilwa-Mafia complex f. Mnazi bay - Ruvuma estuary complex.	a.-d. Fish stock and biological productivity indicators b.-d. Contributing rivers not known	a.d. Fish landing declining over the years – 10,000 t/yr e-f. Biodiversity loss in mangroves, coastal forests, coral habitats	8	Kenya Fisheries Department records; KMFRI database; Muthiga & McClanahan (1987); Wells & Sheppard (1988); McClanahan & Mutere (1994); McClanahan & Obura (1995); Watson (1996); Glaesel (1997); Mwatha (1998); Malleret-King (2000); Ochiewo (2001). e. IUCN (1996); Ngusaru *et al.* (2001)
Salinisation	a. Tana b.Sabaki c. Rufiji delta				c.Tafe (1990); Ngusaru *et al.* (2001)
Human health issues	a.Tana b.Sabaki c.Umba estuary/ Vanga d. Rufiji-Kilwa-Mafia complex e. Ruvuma estuary	Not known but there are: a. Increasing conflicts resulting in loss of human lives a & c. Increased occurrence of water-borne diseases a & c. Reduced productivity due to ill health.		8	a-c. Ochiewo (2001) d-e. Ngusaru *et al.* (2001)

Table RA 6.2. East Africa: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact *versus* catchment size class

P = progressive, **D** = distinct

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km^2	Medium basins 10 000 – 200 000 km^2	Small basins: > 10 000 km^2		
Damming	Retention of sediment Retention of nutrient Modification of the water cycle	-	**medium**	**major**	Coastal erosion Nutrient depletion Salinisation of estuaries and ground water	**P/D**
Deforestation	Increase in sediment run off Increase in sediment loads	-	**major**	**major**	Coastal siltation Smothering of coral reefs	**P**
Agriculture	Increased fertilizer and pesticide residues BOD effluent increase Increased soil erosion Increased water abstraction	-	**medium**	**major**	Pollution Eutrophication Poor water quality Coastal siltation and loss of biodiversity Reduced river flow	**P/D**
Urbanisation	Nutrient increase and increased discharge of metal-rich and BOD-rich wastes (sewage) Increased water abstraction	-	**medium**	**major**	Deterioration of water quality Heavy metal pollution Accelerated rates of biodiversity loss Saline intrusion of groundwater	**D/P**
Industrialisation	Increased waste and thermal pollution, water abstraction	-	**medium**	**major**	Heavy metal pollution and reduced discharge	**P**

Table RA 6.3. East Africa: Linking coastal issues/impacts and land-based drivers at the catchment scale

*Overview and qualitative ranking on catchment scale. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impacts/Issues	Drivers	Local catchment		Trend expectations	References/Data sources
		Tana River	**Impact Category***		
Erosion	Damming		7	⇑	Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979); Denga *et al.* (2000)
	Deforestation		8	⇑	Gibb (1959); Dunne (1974, 1975); ILACO (1971); Ewbank & Partners (1974); Edwards (1979)
	Urbanisation		6	⇑	Denga *et al.* (2000)
	Industrialisation		5	⇑	Ewbank & Partners (1974)
Sedimentation	Damming		8	⇑	ILACO (1971); Ewbank & Partners (1974)
	Agriculture		6	⇑	Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979); UNEP (1998); Denga *et al.* (2000)
Pollution	Industrialisation		4	⇑	
	Urbanisation		5	⇑	
	Agriculture		7	⇑	Dunne (1974, 1975); Edwards (1979); Denga *et al.* (2000)
Biodiveristy/ productivity loss	All drivers listed above	Siltation in Ungwana Bay	7	⇑	Refer to Table 1; Njuguna (1991); Raal & Barwell (1995); Knocker (1998)
Salinisation	Damming		?	⇑	
		Sabaki River	**Impact Category***		
Erosion	Damming	Shoreline progradation and harbour siltation at Malindi	7	⇑	Dunne (1974, 1975); UNEP (1998); Denga *et al.* (2000);
	Deforestation		7	⇑	
	Urbanisation		7	⇑	
	Industrialisation		6	⇑	
Sedimentation	Damming		5	⇑	Arthurton (1992); McClanahan & Obura (1995); Kairu & Nyandwi (2000)
	Deforestation		7	⇑	

Table RA 6.3. East Africa, continued.

Coastal Impacts/Issues	Drivers	Local catchment		Trend expectations	References/Data sources
		Sabaki, continued.			
	Agriculture		7	⇑	
Pollution	Industrialisation		6	⇑	
	Urbanisation		6	⇑	
	Agriculture		6	⇑	Dunne (1974, 1975); Denga *et al.* (2000)
Biodiveristy/ productivity loss	All drivers listed above	Malindi Bay coral reef smothering	7	⇑	Refer to Table 1; Njuguna (1991); Raal & Barwell (1995); McClanahan & Obura (1995); Knocker (1998)
Salinisation	Damming			⇑	
		Rufiji River	**Impact Category**		
Erosion	Damming	Dams proposed	7	⇑	Rogers (1977); Euroconsult/DHV (1980); Atkins (1981), Klomp (1985); Mwalyosi (1988, 1990, 1993); Semesi (1992); Fisher *et al.* (1994); Clarke & Dickinson (1995); TCMP (2000, 2001); Ngusaru *et al.* (2001)
	Deforestation	Extensive forest clearance	7	⇑	
Sedimentation	Deforestation		7	⇑	
	Agriculture		7	⇑	
Pollution	Fisheries	Prawn farm development	8	⇑	Bernacsek (1980); Boyd (1996); Kulindwa (2000); TCMP (2000, 2001)
	Human settlement	Population growth	7	⇑	Kulindwa (2000); TCMP (2000, 2001); Ngusaru *et al.* (2001)
	Agriculture	Use of toxic pesticides	6	⇑	Mwalyosi (1990) ; Kulindwa (2000); TCMP (2000, 2001)
Biodiveristy/ productivity loss	All drivers, especially human settlement and fisheries	Prawn farm development Mangrove clearance Increasing water abstraction	7	⇑	CFP/NORAD (1991); Semesi (1991, 1997); IUCN (1996); IUCN & Rufiji Administration (1997); Ngoile & Kiwia (1996); TCMP (2000, 2001); Ngusaru *et al.* (2001)
Human health issues			7	⇑	Wagner *et al.* (1998); TCMP (2000, 2001); Ngusaru *et al.* (2001)

Table RA 6.4. East Africa: Linking coastal issues/impacts and land-based drivers at the sub-regional scale.

Overview and qualitative ranking on sub-regional scale. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impact/ Issues	DRIVERS	Sub-regional		Trend-expectation	References/ Data sources
		East Africa	Category (1 low – 10 high)		
Erosion	Damming		7	⇑	Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979); Denga *et al.* (2000)
	Deforestation		7-8	⇑	Gibb (1959); ILACO (1971); Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979)
	Urbanisation		6-7	⇑	Denga *et al.* (2000)
	Industrialisation		5-6	⇑	Ewbank & Partners (1974)
Sedimentation	Damming		5-8	⇑	ILACO (1971); Ewbank & Partners (1974)
	Deforestation		7	⇑	Dunne (1974, 1975); Edwards (1979)
	Agriculture		6-7	⇑	Dunne (1974, 1975); Ewbank & Partners (1974); Edwards (1979); UNEP (1998); Denga *et al.* (2000)
Pollution	Agriculture		7	⇑	Dunne (1974, 1975); Edwards (1979); Denga *et al.* (2000)
	Urbanisation		5-6	⇑	
	Industrialisation		4-6	⇑	
Biodiversity loss	Damming Deforestation Agriculture Urbanisation Industrialisation		7	⇑	Refer to Table 1; Njuguna (1991); Raal & Barwell (1995); Knocker (1998)
Salinisation	Damming		?	⇑	
Human health issues					

Table RA 6.6. East Africa: Scientific and/or management responses to coastal impact/issues at catchment and sub-regional scales.

River catchment	RESPONSE catchment scale		RESPONSE Sub-Regional	
	Scientific	**Management**	**Scientific**	**Management**
Kenya coast including Tana and Sabaki (Athi, Galana) river basins	EU-STD II-III and EU-RTD IV project, IOC-SAREC, UNEP-UNESCO, NWP-KWS, Tana Primates World Bank-GEF	Coast Province Administration, District Development Planning, Local Government Authorities, Tana and Athi Rivers Development Authority	UNEP-BADC Eastern Africa Atlas of Coastal Resources – Kenya (1998), – Tanzania (2001). IOC-UNESCO Guidelines for the study of shoreline change in the Western Indian Ocean Region (Kairu & Nyandwi, 2000). Establishment of IOC Western Indian Ocean regional office in KMFRI, Mombasa.	National Environment Management Council (NEMC), Tanzania. Coast Development Authority, Kenya. Kenya Wildlife Service.
Rufiji	• NEMC,TCMP - GISD project (USAID) • REMP (IUCN) • RUBADA • Mangrove management project (NORAD) • FRONTIER • University of Dar es Salaam • RIPS (FINIDA) • WWF-Eco region project • Sida-SAREC • Rufiji Flood Plain Project (Irish and Netherlands)	• Rufiji Basin Development Program • Rufiji Environmental Management Program • Mangrove Management Program • Marine and Coastal Research • Rural Integrated Program Support • Coastal Forest Conservation • Rufiji Flood Plain Project • Biodiversity Loss • EIA for Damming • Pesticides and agrochemicals impact on coastal environment • Impact of Industrial effluents through Rufiji River to the coastal environment • Socio-economic impact Assessment		

Table RA 6.7. East Africa: Hot spots of land-based coastal impact and gaps in understanding as well as a first overview of issues to be addressed in future research.

River catchment	Hot spot catchment scale		Hot spot Sub-regional/ Country scale		Hot spot Regional scale	
	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach
Tana River	• Hydrology, hydrodynamics and water circulation • Deterioration of water quality • River and marine biodiversity loss • Population dynamics of the key fisheries • Socio-economic situations	• Measurements and modeling studies-river discharge dynamics, sediment loads and water exchange in the estuary • Monitoring water quality parameters in the Tana delta • Assessment of river and marine biodiversity • Assessment of dynamics of key commercial species • Study existing socio-economic set-up in the river basin and along the coastal zone				

Table RA 6.7. East Africa, continued.

River catchment	Hot spot catchment scale		Hot spot Sub-regional/ Country scale		Hot spot Regional scale	
Rufiji River	• Nearshore oceanography and coastal processes • Hydrogeology • Sedimentation and water quality related problems • River and marine biodiversity loss and conservation • Trade dynamics of natural resources • Agriculture and livestock development and impact on the environment • Mangrove and estuarine dynamics • Relation between fisheries and the flooding regime • Dynamics of the natural forests and woodlands • Identification of urgent conservation measures	• Fundamental research to support the understanding of intricate ecological processes, which is the key to defining sustainability. • Applied research with case studies of processes (of specific issues or problems of the dynamics) • Predictive models (natural and human-induced ecosystem changes) • Monitoring and feasibility studies • Flows – which include materials, and elements through the system (pollutants, DDT, nutrients, water) • Stocks – in terms of quantity of environmentally provided assets such as forests, wildlife, fisheries, water, wetlands, soil, atmosphere. These provide a flow of useful goods or services. • Status – in terms of measures of specific phenomena (e.g. levels of land based inputs to the sea, carrying capacity, water requirements for the survival of ecosystems, health etc)				

Regional assessment Tables 7. Central/south Mozambique, *by F. Tauacale*

Table RA 7.1. Central/southern Mozambique: Major coastal impacts/issues and critical thresholds
*Overview and qualitative ranking on catchment scale: Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal IMPACT/ ISSUE	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold	Impact category*	References/ Data source
Erosion	a. Zambezi b. Limpopo c. Incomati estuary	a. unknown c. unknown	a. unknown c. 4km damming, erosion becomes a continuous process	8 8	a. Gove (1993) c. MICOA (1998)
Sedimentation	a. Zambezi b. Limpopo c. Incomati	a. unknown	a. unknown	a.8 c.9	a. Balek (1972) c. MICOA (1998)
Eutrophication	a. Zambezi b. Limpopo c. Incomati d. Xinavane, over 80km of estuary	a-c. unknown d. Anoxia or low Oxygen in estuary	a-c. unknown d. increased nutrient	a. 2 d.10	a. Mordosova (1980) b. Mordosova *et al.* (1980); Munga (1987); Caralap *et al.* (1993); Masundire & Matiza (1995)
Pollution	a. Zambezi b. Limpopo c. Incomati d. Maputo Bay	a,b. unknown	a,b. unknown	d. 8	d. Hoguane (2000)
Biodiveristy loss (Loss of biological function)	a. Zambezi delta b. Sofala Bank c. Limpopo d. Incomati	a,b. Ecosystem collapse – sardine fishery, *Posidonia* disappeared, primary productivity severely reduced - prawn fisheries	a,b. exceeded	a,b. 10	a,b. Da Silva (1986); Gammelsrod (1992, 1996); Hotton & Munguambe (1998); Guale (2000)
Salinisation	a. Zambezi b. Limpopo c. Incomati to 80km from mouth	a. unknown b. unknown	a. unknown b. unknown	c. 10	c. Matola, J. (1999)
Human health issues	a. Zambezi b. Limpopo c. Incomati	a. unknown	a. unknown		

Table RA 7.2. Central/southern Mozambique: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact versus catchment size-class.

P = progressive, **D** = distinct

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km^2	Medium basins 10 000 – 200 000 km^2	Small basins: > 10 000 km^2		
Damming	Reduction in water flow Reduction in sediment discharge Nutrient retention	**major**	**major**	-	Increased salinisation Changes in coastal morphology, erosion Nutrient depletion	**P**
Deforestation	Modification of vegetation cover and runoff, soil erosion	**minor? (medium)**	**major**	-	Sedimentation and habitat modification Erosion evident where mangroves have been clear felled	**P**
Agriculture	Increased water abstraction Decrease in BOD effluent Increased soil erosion and modified runoff; increased nutrient and pesticide fluxes	**minor**	**medium**	-	Salinisation Eutrophication, increasing anoxia Habitat loss Degradation in groundwater quality	**P**
Urbanisation	Increased sewage discharge, pollution in Maputo Bay	**minor**	**medium**	-	Deterioration in surface and groundwater quality; local eutrophication	**D/P**
Industry	Discharge of toxic substances in estuary of Maputo Bay	**minor**	**minor**		Accumulation of pollutants in coastal sediments	**D/P**

Table RA 7.3. Central/southern Mozambique - Linking coastal issues/impacts and land-based drivers at the catchment scale.

Overview and qualitative ranking on catchment scale: Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Zambezi			
Erosion	Damming	Reduced river inflow has resulted in changes in habitat characteristics, e.g., changes the regime and characteristics of the substratum and increasing erosion downstream.	7	⇑	Gove (1993); Masundire & Matiza (1995)
Sedimentation	Damming	Alterations in river flow regime has altered the sedimentation processes downstream and in Zambezi delta, altering the duration and timing of mouth closure/opening	3	⇓	Gove (1993); Masundire & Matiza (1995)
	Agriculture	Poor catchment management result in soil erosion downstream and sedimentation in coastal areas (Zambezi delta)	2	⇑	
Loss of habitat /biodiversity	Damming	During flood periods, poor catchment management resulting in high runoff may damage the mangrove and affect productivity of prawn in Zambezi delta.	7	⇑	Balon & Coche (1974); Brinca *et al.* (1986); Da Silva (1986); Gammelsrod (1992, 1996); Timberlake (1998)
	Agriculture	Use of fertilizer and activities in the downstream results in excessive reed growth along the waters of the Zambezi delta	7	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
Stream flow (reduction)	Damming	Poor catchment management results in low flow downstream and sedimentation in coastal areas (Zambezi delta)	9		Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Catchment supports major agricultural activities probably introducing some pesticides to coastal areas.	2?	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)

Table 7.3. Central/southern Mozambique, continued.

Coastal Impact Issues	Drivers	Motivation	Impact Category	Trend expectations	References/Data sources
		Limpopo			
Eutrophication	Agriculture	Poor catchment management and use of fertilizer and activities in the Chokowe scheme results in excessive reed growth along the estuary.	2	⇒	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
Stream flow (reduction)	Damming	Poor catchment management upstream results in low flow downstream.	5	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
		Incomati			
Erosion	Damming	Reduced river inflow has resulted in changes in habitat characteristics, e.g. changes the regime and characteristics of the substratum and increasing erosion downstream.	6	⇑	JIBS (2001)
Sedimentation	Damming	Alterations in river flow regime have altered the sedimentation processes downstream in estuary.	2-3	⇓	
Eutrophication	Urbanisation Agriculture	Use of fertilizer and activities in the Xinavane and Maragra scheme have resulted in excessive reed growth along the floodplain and estuary.	5	⇑	JIBS (2001); SRI (2001)
Salinisation	Damming	Poor catchment management has resulted in low flow downstream and salinisation in estuary areas	8	⇑	SRI (2001)
Pollution (e.g. trace metals, hydrocarbons, pesticides)	Agriculture	Catchment supports major agricultural and mining activities probably introducing some pesticides to coastal areas.	8	⇑	Pers. comm.

Table RA 7.4. Central/southern Mozambique: Linking coastal issues/impacts and land-based drivers at the sub-regional scale.

Overview and qualitative ranking on sub-regional scale. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal Impact/Issues	DRIVERS	Central/south –Mozambique		Trend-expectation	References/ data sources
		Related basins	Category (1 low – 10 high)		
Erosion	Damming	a. Incomati	6-7	⇑	Gove (1993); JIBS (2001)
Sedimentation	Agriculture	a. Zambezi b. Limpopo c. Incomati	2	⇒	Pers. comm.
	Deforestation	a. Limpopo	?		
	Damming	a. Zambezi b. Limpopo c. Incomati	2-3	⇓	Pers. comm.; Gove (1993); JIBS (2001)
Stream flow reduction	Damming	a. Limpopo b. Incomati c. Save	5-9	⇑	Chonguica (1997); UEM (1999); Tauacale (1999); Guale (2000); JIBS (2001); SRI (2001)
Eutrophication	Urbanisation Agriculture	a. Limpopo b. Incomati	2-5	⇒ (⇑)	Pers. Comm.; SRI (2001); JIBS (2001)
Nutrient depletion	Damming	a. Limpopo b. Incomati	5-7	⇑	Mordosova (1980); Mordosova *et al.* (1980); Munga (1987); Caralap *et al.* (1993); JIBS (2001)
Biodiversity loss	Agriculture Damming	a. Limpopo b. Incomati c. Save	5-7	⇑	Brinca *et al.* (1986); Da Silva (1986); Gammelsrod (1992, 1996); SRI (2001)
Salinisation	Damming	a. Incomati b. Pungue c. Buze	8	⇑	Matola (1999); SRI (2001)

Table RA 7.6. Central/southern Mozambique: Scientific and/or management responses to coastal impact/issues at the catchment scale.

River catchment	RESPONSE catchment scale	
	Scientific	**Management**
Incomati	Shared River Initiative Project. RSA. (1999 – 2000) Joint Inkomati Basin study, phase 1-2. Consultec and BKS Acres, Final Report (2001) Country situation Report – water Resources – Mozambique vol.1-3- (1998) MBB Consulting Engineers, Acer (Africa) Environmental Management Consultants, AWARD. 2000. Proposal for the Establishment of Catchment Management Agency for the Inkomati Basin. Final Draft. Prepared for the Inkomati Catchment Management Agency Reference Group, under the auspices of DWAF, Mpumalanga Regional Office. (2000) **DNA**. 1991. Gestao de Recursos Hidricos na Bacia Hidrografica do Incomati. Report 56/91	Shared River Initiative Project. RSA. (1999 – 2000) Joint Inkomati Basin study, phase 1-2. Consultec and BKS Acres, Final Report (2001) Country situation Report – water Resources – Mozambique vol.1-3- (1998). The first phase of a cumulative environmental impact assessment for the Inkomati river basin. (2000) MBB Consulting Engineers, Acer (Africa) Environmental Management Consultants, AWARD. 2000. Proposal for the Establishment of a Catchment Management Agency for the Inkomati Basin. Final Draft. Prepared for the Inkomati; Catchment Management Agency Reference Group, under the auspices of DWAF, Mpumalanga Regional Office. (2000) **DNA** 1991. Gestao de Recursos Hidricos na Bacia Hidrografica do Incomati. Report 56/91
Limpopo	Jamieson, J.G. Planning and management of water resources in Mozambique. DNA (1985) Koudstaal, R. Identification of major issues in Water resources master planning in Mozambique. Delft, Netherlands (1989) DNA, Planning for water resources management. Progress Limpopo Study. Maputo (1991)	Jamieson, J.G. Planning and management of water resources in Mozambique. DNA (1985) Koudstaal, R. Identification of major issues in Water resources master planning in Mozambique. Delft, Netherlands (1989) DNA, Planning for water resources management. Progress Limpopo Study. Maputo (1991)

Table RA 7.7. Central/southern Mozambique: Hot spots of land-based coastal impact, gaps in understanding and a first overview of issues to be addressed in future research.

River catchment	Hot spot catchment scale		Hot spot Sub-regional/ Country scale	
	Key issue, trend and gaps	**Scientific approach**	**Key issue, Trend and gaps**	**Scientific approach**
Zambezi	• Investigate effects of upstream impoundments and flood regulation on the Mozambique coast • Impact of the cessation of silt transport to the Mozambique coast. • Impact of nutrient retention on bio-productivity	• Monitoring and investigative research		
Incomati	• water quantity • water quality • River and marine biodiversity loss • Salt intrusion • Socio-economic situations	• Assessment and modeling studies river health. • Monitoring water quality parameters in Incomati • Assessment of dynamics of salt intrusion and land loss • Study existing socio-economic set-up in the river basin and along the coastal zone	• Deterioration of water quality • River and marine biodiversity loss	• Monitoring water quality parameters in the Maputo Bay • Assessment of river and marine biodiversity
Limpopo	• Floods regulation • Water quantity • Water quality	• Identification of flood plain risk in coastal zone. • Monitoring water quality and biodiversity loss. • Studies of river health.		

Regional Assessment Tables 8. South East Africa, *by A. Forbes*

Table RA 8.1. South East Africa: Major coastal impacts/issues and critical thresholds

*Overview and qualitative ranking 1 = minimum, 10 = maximum

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category	References/ Data source
Erosion	a. Tugela b. Great Fish c. Kromme d. Groot Brak	a. 60% existing flow b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 3 b. 3 c. 2 d. 2	Tugela (Thukela): Begg (1978); See report in press with Nakumura
Sedimentation (e.g., marine sedimentation due to reduced freshwater inflow or from agricultural practices)	a. Tugela b. Great Fish c. Kromme d. Groot Brak	a. 60% existing flow b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 4 b. 2 c. 2 d. 3	Great Fish: Watling & Watling (1983); Allanson & Read (1987); Whitfield (1994); Whitfield, Paterson, Bok & Kok (1994); Allanson & Read (1995); Ter Morshuizen, Whitfield & Paterson (1996); Grange, Whitfield, de Villiers & Allanson (2000)
Eutrophication	a. Tugela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 3 b. 2 c. 2 d. 4	Kromme: Watling & Watling (1982b); Emmerson & Erasmus (1987); Sowman & Fuggle (1989); Adams, Knoop & Bate (1992); Adams & Talbot (1992); Schumann & de Meillon (1993); Jerling & Wooldridge (1994); Heymans & Baird (1995); Baird & Heymans (1996); Quinn, Breen, Hearne & Whitfield (1998); Bate & Adams (2000); Scharler & Baird (2000); Snow, Bate & Adams (2000); Strydom & Whitfield (2000); Wooldridge & Callahan (2000)
Pollution	a. Tugela b. Kariega c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 4 b. 2 c. 2 d. 3	Groot Brak: Day (1981); Watling & Watling (1982a); Morant (1983); Slinger & Breen (1995); Slinger, Taljaard & Largier (1994); Coetzee, Adams & Bate (1997)

Table RA 8.1. South East Africa, continued.

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning	Distance to Critical Threshold (qualitative or quantitative)	Impact category	References/ Data source
Loss of biodiversity (loss of biological function)	a. Tugela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Modified by freshwater input c. Functional but marine-dominated d. Unknown	a. 4 b. 3 c. 5 d. 4	
Human health issues	a. Tugela b. Great Fish c. Kromme d. Groot Brak	a. Unknown b. Unknown c. Unknown d. Unknown	a. Unknown b. Unknown c. Unknown d. Unknown	a. 2 b. 2 c. 2 d. 3	

Table RA 8.2. South East Africa: DPSI matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related coastal state changes and impact versus catchment size-class.

P = progressive, **D** = discrete

Driver	Pressures	State change Qualitative index			Impact on the coastal system	Time scale
		Large basins > 200 000 km²	Medium basins 10 000 – 200 000 km²	Small basins: < 10 000 km²		
Damming	High freshwater retention in semi arid situation (e.g., Kromme)	-	**medium**	**minor - major**	In some cases no freshwater discharge year-long Nutrient depletion in estuaries and coastal waters	**D**
Deforestation	Modification of vegetation cover and soil erosion	-	**medium**	**major**	Increased sediment discharge and siltation where free from impoundment	**P**
Agriculture	Sediment mobilization and modified runoff Increased nutrient and pesticide fluxes	-	**medium**	**medium**	Changes in sediment flux, eutrophication, degradation of groundwater quality	**P**
Urbanisation	Increase in sewage, deterioration in water quality	-	**minor**	**minor - major**	Range from high impact near cities (Durban) to pristine conditions further distant	**D/P**
Industrialisation	Discharge of toxic substances, deterioration in water quality	-	**minor**	**minor - major**	Pollution of estuarine waters and sediments	**D/P**

Table RA 8.3. South East Africa: Linking coastal issues/impacts and land-based drivers at the catchment scale.

Overview and qualitative ranking on catchment scale 1 = minimum, 10 = maximum

Coastal impacts/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		Tugela River	**Impact Category**		
Erosion	Damming	Sediment retention	2-3	⇒/⇑	See Table 1
	Deforestation	Few natural forests	2	⇒	*South East* Africa
	Agriculture		5	⇑	
	Urbanisation		2	⇑	
	Industrialisation		2	⇑	
	Climate change	Unknown	?	?	
Sedimentation	Damming	Sediment retention; coastal erosion	3	Probable ⇑	
Eutrophication	Urbanisation	Localised	3	⇑	
	Agriculture	Localised – generally low intensity	4	⇑	
Pollution	Industrialisation	Localised – low industrialisation	3	⇑	
	Urbanisation	Localised	3	⇒/⇑	
	Mining	Localised	3	⇒	
Nutrient depletion	Damming	Probable estuary & offshore	4	⇑	
Biodiversity loss		Localised	2-3	⇑	
Human health issues		Local contamination of water supplies – cholera endemic	4-5	⇒	
		Great Fish/Kromme/Groot Brak Rivers	**Impact Category**		
Erosion	Damming		2	⇒	
	Deforestation	Few significant forests	2	⇒	
	Agriculture	Localised	3	⇒	
	Urbanisation	Very localised	3	⇒	
	Industrialisation	Localised	2	⇒	
	Climate change	Unknown	Unknown	?	
Sedimentation	Damming	Loss of flood scour; followed by estuarine sediment build-up & mouth closure	1-4	⇒	

Table RA 8.3. South East Africa, continued.

		Great Fish/Kromme/Groot Brak Rivers continued.	Impact Category	Trend expectations	References/ Data sources
Eutrophication	Urbanisation	Localised	1-4	⇒	
	Agriculture	Localised	1-4	⇑	
Pollution	Industrialisation	Localised	1-3	⇒	
	Urbanisation	Localised	1-3	⇑	
	Mining	N/A	0	?	
Nutrient depletion	Damming	General	5-8	⇑	
Biodiversity loss		Ecosystem switch	5-8	⇑	
Human health issues		Variable	3-7	⇒/Increase	

Table RA 8.4. South East Africa: Linking coastal issues/impacts and land-based drivers at the sub-regional scale.
Overview and qualitative ranking on sub-regional scale: 1 = minimum, 10 = maximum

Coastal Impact/Issues	DRIVERS	Sub-regional		Trend-expectation	References/ Data sources
		South eastern Africa	Category		
Erosion	Damming	Very localised on coast	1	Possible⇑	See Table 1 *South East* Africa
	Deforestation	Localised	1	⇒	
	Agriculture	Wide-spread	2	⇒	
	Urbanisation	Localised	1	⇑	
	Climate change	Unknown	?	?	
Sedimentation	Damming	Estuaries – loss of flood scour	4	⇑	
	Deforestation	Localised	2	⇒	
	Agriculture	As in estuaries	4	⇑	
Eutrophication	Damming	N/A	2	⇒	
	Agriculture	Unusual – localised estuaries	3	⇑	
	Urbanisation	Localised – primarily estuaries	3	⇑	
	Industrialisation	Localised	4	⇑	
Pollution	Agriculture	Localised	4	⇒	
	Urbanisation	Localised	0-8	⇒	
	Industrialisation	Localised	0-7	⇒	
	Mining	Very localised	0-4	⇒	
	Fisheries	Rare	0-2	⇒	
Biodiversity loss	Damming	General	0-5	⇑	
	Deforestation	Rare	0-2	⇒	
	Agriculture	Localised	0-3	⇑	
	Urbanisation	Localised	0-7	⇑	
	Industrialisation	Localised	0-6	⇑	
	Mining	Very localised	0-3	⇒	
	Fisheries	Wide-spread	2-8	⇑	
Nutrient depletion	Damming	Primarily estuaries, localised offshore	1-4	⇑	
Human health issues		Localised – mainly estuaries	1-3	⇑	

Table RA 8.6. South East Africa: Scientific and/or management response to coastal impact/issues in African coastal zones on catchment, sub-regional and regional scales.

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional/ Country Scale (e.g., in SADC region)	
	Scientific	Management	Scientific	Management
Tugela	Incorporation of estuary as well as coastal and offshore environments into the E.I.A. of the proposed T.W.P. (Thukela Water Project) by the South African Department of Water Affairs and Forestry. Report in press.	Proposed consideration of the design of the impoundments and water release patterns to allow minimum disruption of natural flow patterns.	Marine processes dominate the very open, high energy South African coastline, with the result that catchment events are far more apparent in estuaries than offshore, although turbidity plumes are a feature of the KwaZulu-Natal coast during the summer rainfall period. Consideration of the effects of land runoff have not been a priority until very recently, culminating in the T.W.P. E.I.A. referred to in this table. Marine research dates back at least a century while organized estuarine studies only began in about 1950 (Day 2000). For reasons outlined above the estuarine research component shows far more focus on the land-water interaction and this is reflected in Whitfield's (2000) summary of available estuarine literature and the synthesis of available knowledge by Allanson & Baird (1999).	Estuarine studies have, in recent years, focussed progressively more on management objectives, practicalities and techniques and have been fortunate in being able to build on a strong research foundation. The incorporation of this knowledge into management policy and action is now a major priority. Research and management is strongly supported by local funding agencies including the Department of Environmental Affairs and Tourism, the National Research Foundation, The Water Research Commission and the Department of Water Affairs and Forestry (at times with European and British subvention). These organizations work closely with the Consortium for Estuarine Research and Management (CERM) a voluntary network of about 80 researchers working on estuaries throughout the country (For review see SA Waterbulletin 27(6)). A significant attempt to bring estuarine science to the manager has been produced by Breen & McKenzie (2001) which incorporates a summary of the relevant legislation which provides for protection of both the estuarine and the coastal environment. Legislation is covered in more detail by Glazewski (2000)and policy and implementation is reviewed by Boyd, Barwell & Taljaard (2000), Glavovic (2000) and the Department of Environmental Affairs & Tourism (2000).
South African estuaries in general				

Table RA 8.7. South East Africa: Hot spots of land-based coastal impact, gaps in understanding and an overview of issues to be addressed in future research.

River catchment	Hot spot Catchment scale		Hot spot Sub-regional/ Country scale	
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
Tugela, Mkomazi and other major east coast rivers	Effects of land-derived runoff on coastal marine productivity in oligotrophic coastal environments	Primary production studies in the water column; effects of floods, sediment plumes on biological processes in affected areas.		
Rivers (Mkuzi, Mfolozi, Hluhluwe) associated with the Greater St Lucia Wetland Park (a RAMSAR site)	Long term effects of flow reduction and droughts on biological processes in the St Lucia lake.	Analysis of nutrient sources and cycles; levels of primary production in the water column and fringing vegetation; effects of different salinity levels on carbon fixation and sources, carbon and nitrogen flow patterns based on light isotope analyses.		

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APPENDICES
Appendix I

Human dimensions of land-based fluxes to the coastal zone: the LOICZ-Basins approach
by H.H. Kremer, Wim Salomons and C.J. Crossland

The following appendix provides an introduction in methodology of the regional assessment and synthesis of human dimensions of land-based fluxes to the coastal zone as performed in the LOICZ-Basins core project. In using a common methodology, harmonized assessment protocols and project designs for research on global scales, the LOICZ-Basins framework aims to assist in interregional exchange and acquisition of funding opportunities on local, sub-regional and regional scales.

Background
Coasts worldwide are subject to many pressures which are expected to continue or increase in the future. Natural flows of water, nutrients and sediments to the coast are largely and increasingly influenced by past and planned physical changes in rivers (e.g., damming). In addition, the increase in tourism, fisheries, urbanization and traffic will offer challenges for the coastal zone managers and regulators. The management issues and their solutions require an integrated approach of the natural and socio-economic sciences (Turner *et al.* 1998; Salomons *et al.* 1999). Numerous studies (often mono-disciplinary) have been conducted to deal directly with these issues but could benefit from more integrated assessment. This integration of the results of past studies requires a simple and harmonized framework for assessment and analysis. For the integration LOICZ-Basins uses the DPSIR framework:

LOICZ-Basins faces three major challenges:

1) to determine the time delay between changes in land-based material flows (due to socio-economic activities, morphological changes or regulatory measures) and their impact on the coastal zone system.
2) to generate an improved understanding of the complexities of the coastal sea environments and to derive from this complex environment the "critical loads".
3) to consider the multiplicity of interests and stakeholders affected by transboundary issues, particularly when local, regional, national, and multi-national governmental bodies with conflicting interests are involved.

The DPSIR framework

The Driver-Pressure-State-Impact-Response or DPSIR scheme (Turner *et al.* 1998; Turner and Bower 1999), provides a standardised frame for site assessment and evaluation. It ultimately enables the calculation and modelling of the impacts of change on the delivery and use of environmental goods and services expressed in scientific and monetary terms. The scheme sets up a platform for independent review and feedback evaluation of political and managerial response and options. The elements of this framework are:

Drivers: resulting from societal demands the sectoral activities with consequences for the coastal zone include:
- urbanisation
- aquaculture
- fisheries
- oil production and processing
- mining
- agriculture and forestry
- industrial development
- land use change.

Pressures: processes affecting key ecosystem and social system functioning (i.e., natural and anthropogenic forcing affecting and changing the state of the coastal environment):

- damming and other constructions
- river diversion, irrigation and water abstraction
- industrial effluents (industrialisation), agricultural and domestic wastes (urbanisation)
- navigation and dredging
- sea-level rise induced by land-based activities and affecting the coastal zone (e.g., decrease of riverine sediment load leading to instability of coastal geomorphology)
- other forcing functions (not primarily anthropogenic) such as climate change.

State and State change: the indicator functions and how they are affected:

- water, nutrient and sediment transport (including contaminants where appropriate) observed in the coastal zone as key indicators for trans-boundary pressures within the water pathway. Indicators are designed to give an overview of the environmental status and its development over time and enable ultimately derivation of critical load information
- geomorphologic settings, erosion, sequestration of sediments, siltation and sedimentation
- economic fluxes relating to changes in resource flows from coastal systems, their value, and changes in economic activity including the valuation of natural resources, goods and services.

Impact: effects on system characteristics and provision of goods and services:

- habitat alteration
- changes in biodiversity
- social and economic functions
- resource and services availability, use and sustainability
- depreciation of the natural capital.

Response: action taken on political and/or managemnet level:

- scientific response (research efforts, monitoring programs)
- policy and/or management response to either protect against changes such as increased nutrient or contaminant input, secondary sea level rise, or to ameliorate and/or rehabilitate adverse effects and ensure or re-establish the chance for sustainable use of the system's resources.

The pressures are manifold, so we narrow them down within the LOICZ context, which deals with changes in biogeochemical cycles as major indicators. The LOICZ-Basins project therefore deals with the impact of human society on the material transport such as water, sediments, nutrients, heavy metals and man-made chemicals to the coast. It assesses the loads and their coastal impact and tries to provide feasible management options together with an analysis of success and failure of past regulatory measures. Since changes in fluxes are mostly land or catchment-based, the catchment–coastal sea system is treated as one unit – a water continuum. In applying this scale to loads and coastal change phenomena this means that beyond activities from agriculture, fisheries, urban development, industry, transport, tourism also morphological changes made to a catchment (e.g. damming) have to be taken into account.

In particular the following parameters will be assessed:

- material flow of water, sediments, nutrients and priority substances (past, current and future trends);
- socio-economic drivers which have changed or will change the material flows;
- indicators for impacts on coastal zone functioning; and to derive from them
- a "critical load" for the coastal zone and "critical thresholds" for system functioning.

Linking coastal response to socio-economic drivers

This critical load and threshold concept being developed within the UN/ECE CLRTAP convention will develop this link. (The "United Nations Economic Commission for Europe's convention on Long-Range

Transboundary Air Pollution" has held several workshops and produced handbooks on the critical load concept for terrestrial and freshwater systems. In LOICZ-Basins these concepts are extended to the marine environment). In a systems approach it can be used (as has been done for atmospheric pollution abatement) for a cost-benefit analysis of management options. Scenario-building is an integral part of this analysis. Critical loads provide key information for the development and application of indicators for monitoring purposes as required, for example for the implementation of the Coastal Global Observation System, C-GOOS, of UNESCO's IOC.

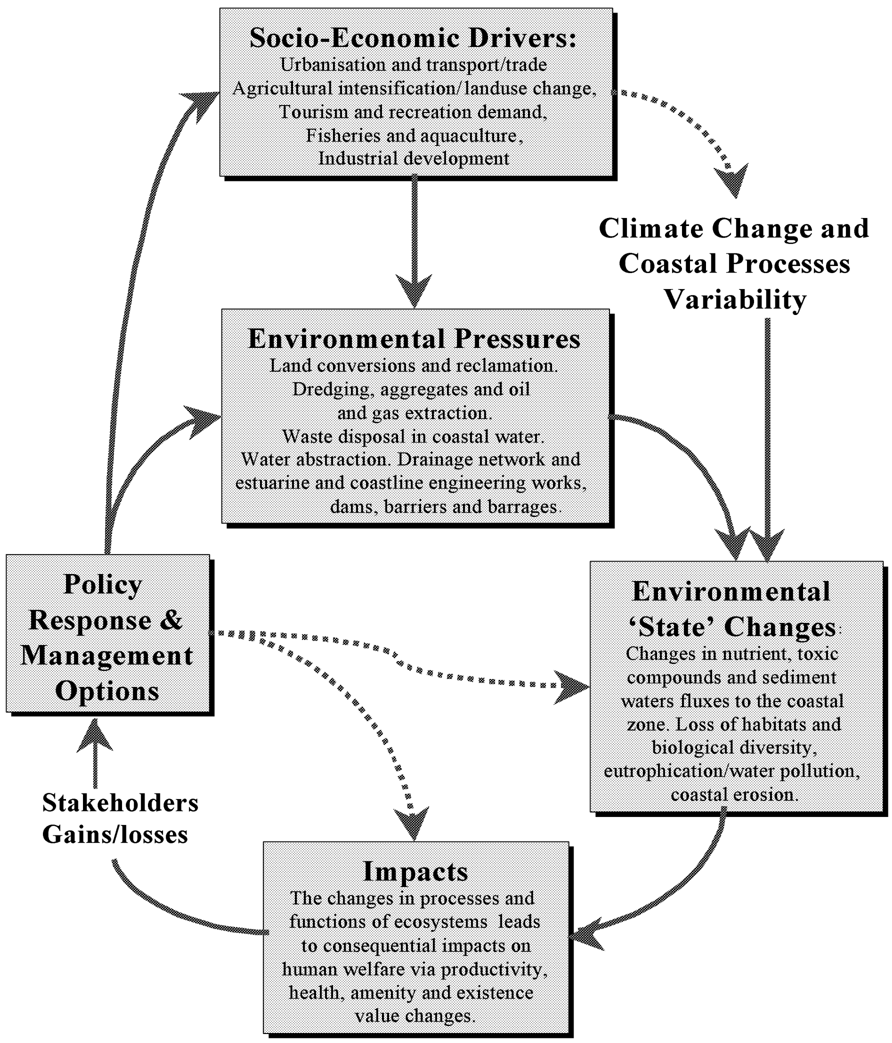

Figure A1.1. Description of the Driver-Pressure-State-Impact-Response (DPSIR) Framework.

LOICZ-Basins employs different approaches to identify **targets and indicators** for the coastal response:

- The most simple "policy-oriented" approach is taking the critical loads which have been agreed upon in international treaties (e.g. the 50% reduction scenario within the Rhine Action Plan, also adopted for the North Sea).
- The "ecosystem" approach uses historical data on the response of the coastal system to changing loads and identifies indicators. This approach will incorporate an attempt to discriminate between the natural state and an anthropogenically altered state.
- The "regional management" approach is based on consultation with local authorities and identifies their criteria for indicators or critical loads. This incorporates other indicators than those based on scientific arguments alone.

The indicators and targets will be used to derive critical concentrations. Taking into account transformations and dispersion in the coastal environment, a critical load to the coastal zone can be calculated. This critical load, the **critical outflow** of the catchment, is a combination of inputs by socio-economic activities and transformations in the catchment and its delta/estuary. Once these links and the transformations of the loads have been established it will be possible to carry out scenarios for cost-benefit analysis and trade-offs. This will require the integration of existing modelling tools from the natural and social sciences.

The DPSIR framework is applied to determine critical loads of selected substances, under different development scenarios, with diverse biophysical and socio-economic settings, triggering the discharge into the coastal seas. It aims to provide the interdisciplinary platform for participatory approaches jointly with natural, social and economic scientists, and to incorporate representatives of stakeholders including industry, agriculture, environmental organizations and citizens.

Large catchments seem to be obvious examples to be addressed within a global LOICZ synthesizing effort (e.g. Amazon, Nile, Yangtze, Orinoco). However, from the pesrpective of coastal change, the major influence from land-based flows is generated in small to medium catchments with high levels of socio-economic activity. Changes in land cover and sectoral use need much shorter time-frames to translate into coastal change and usually exhibit more visible impacts than in large catchments where the "buffer capacity" against land-based change is higher simply as a function of catchment size. Thus, small and medium catchments are of priority to the global LOICZ-Basins assessment. They dominate the global coastal zone (in Africa, for example, they characterize extensive parts of monsoon-driven runoff to the Indian Ocean). In island-dominated regions such as the South Pacific or the Caribbean frequently a whole island is a catchment affecting the coastal zone and influences are generated by both anthropogenic drivers and global forcing.

The approach

Regional networks, assessment workshops/desk studies

Through two-stage regional workshops, LOICZ-Basins builds up regional multidisciplinary networks of scientists who bring their experience and existing information into the synthesis process. The first workshop identifies the pertinent regional issues and provides a first ranking order of current and predicted impacts with trend analysis, based on expert judgement and published scientific information. A second workshop finalizes the first regional synthesis, improves the geographical and thematic coverage and assists in preparing research proposals for local and regional funding. Emphasis is given to close coupling of biogeochemical and physical sciences with human dimensions. Workshops have been held and networks established in Europe, Latin America, East Asia and Africa, while desk studies cover the Caribbean, Oceania and the Russian Arctic. In February 2001 the European Catchments (EuroCat) project, funded by the European Union, started (http://www.iia-cnr.unical.it/ EUROCAT/project.htm) as a direct result of a LOICZ assessment. The EuroCat design, objectives and modelling approaches serve as templates for the development of other regional catchment-coastal zone projects currently being developed for Africa, Latin America and East Asia.

A **LOICZ Basins** WWW page is now available at the GKSS Research Center, Geesthacht, Germany, (http://w3g.gkss.de/projects/loicz_basins/) and through the LOICZ web-site (www.nioz.nl/loicz/). It is updated continuously and provides copies of reports for downloading.

Proposals and projects that develop from regional LOICZ-Basins efforts contribute to the global LOICZ assessment. They also contribute to the Integrated Coastal Area Management initiative, ICARM, as well as to the Coastal GOOS "Global Ocean Observing System" of UNESCO/IOC. Links to the typology up-scaling effort considering global river run off and coastal biogeochemistry (a joint project of LOICZ and BAHC through the University of New Hampshire) are being pursued. Watching briefs exist with other global efforts such as GIWA, the WWAP and Millennium Assessment. Increasing the links with the Regional Seas initiatives under UNEP and the GPA is under consideration.

The framework for LOICZ Basins Synthesis and Project Development

Since LOICZ-Basins workshops have a regional focus, assessment and ranking follow a heirarchy of scales finally allowing a full regional picture to be generated – the scales increase from:

- ➢ local catchments via
- ➢ sub-regional or provincial scales up to
- ➢ regional scale which could be a country (e.g., Brazil) or a sub-continent or continent.

To facilitate thinking and to guide the evaluation of existing information, the Driver/Pressure/State/ Impact/Response scheme (DPSIR) has proven to be an appropriate descriptive framework. The steps taken are:

a) set up a **list of coastal change issues** of and **related Drivers** in the catchment (plenary-task).
b) characterize and rank the various issues of change based on either **qualitative information** (i.e., expert judgement - if there are no hard figures) or **hard data** coming from investigations or archived material; this includes identifying **critical load** and **threshold** information for system functioning.
c) derive a list of current or prospective **"hot spots"** representative of a type or class of catchment-coast system, from which to develop a **proposal** for future interdisciplinary work.

In other words LOICZ-Basins aims to provide an **expert typology** of the current state and expected trends of coastal change under land-based human forcing and natural influences. The assessment follows a set of key questions which cover the various aspects and scales of the DPSIR analysis and follow a sequence of **assessment tables**, participants are asked to fill in prior to the workshops. A generic scheme is shown below. All major assessment tables closely follow this scheme, and allow inner and interregional comparison within the global LOICZ-Basins effort, although the entries to the tables can be different.

Up-scaling process

Drivers ranked for importance by expert judgement

Coastal issues	**Drivers***	**Local catchment level (allowing within- and between-catchment comparison)**		**Sub regional level (e.g. by country or considering open** versus **enclosed seas)**		**Region level (e.g., Africa)**
Eutrophi-cation	Damming	River A	Trends or Ranking	Sub-region 1 (Rivers A-D)	Trends or Ranking	
Erosion	e.g. Water Abstraction	River B				
Loss of Biodiversity						

***** = see comments on this driver identification and ranking on the following pages.

Figure A1.2. Basic schema of assessment tables.

Ranking and classification

The OSPAR 2000 quality status report (http://www.ospar.com) lists human pressures on the coastal sea in a ranking order with four classes according to their relative impact on the regional ecosystem - including sustainable use. Pressures are attributed to various drivers or pressure classes.

Table A1.1 shows a few examples compiled along the OSPAR guidelines, adapted to fit the LOICZ-Basins concept. It focuses on issues which link to land-based activities.

Table A1.1. Examples of impacts, pressures and driver/pressure settings in the LOICZ context.

Impact priority	Priority Classes of Human Pressures	Driver/Pressure settings - sectoral; land- or catchment- or sea-based
A (highest impact)	Input of organic contaminants – land-based	Various economic sectors
	Inputs of nutrients – land-based	Various sectors, urbanization, (wastewater, agriculture)
B (upper intermediate impact)	Input of oil and PAH – land-/sea-based	Oil industry/Shipping
	Input of other hazardous substances – land-/ sea-based	Industry/Shipping/various sectors
C (lower intermediate impact)	Input of nutrients, organic material, antibiotics etc.	Mariculture
	Mineral extraction – land/ sea based	Engineering, Mining
	Inputs of radio nuclides from land	Energy and other sectors
D (lowest impact)	Input of waste/litter	Recreation, Tourism

From these and other examples, adapted to the LOICZ needs and relying strongly on regional expert judgement and - if available - regional quality standard protocols and agreements, the LOICZ-Basins task group has developed a set of **Basins Regional Assessment tables** for global application.

LOICZ-Basins Regional Assessment Tables (RA 1- 7) and key questions for workshops, synthesis and project development

The tabulated DPSIR analysis has proven to be an appropriate descriptive framework for this purpose. The questions leading through the tables have usually been addressed in the first phase of the Basins worklshops. The tables ensure a standardize approach within the global LOICZ-Basins effort. They allow integration of the regional assessments and expert typologies into the global scales and help to fill gaps and harmonise the synthesis. Data included in the first workshop are reviewed and confirmed in light of new information delivered to the second workshop. Detailed source references for data or critical load information are included wherever possible.

Table Input

Major data needed for the assessment are material flows and loads (historic data and those of relatively unimpacted systems if possible). Fluxes to be considered are:

- Water
- Sediments
- N, P, C (Si)
- Contaminants

The trend information on expected changes in the DPSIR scenarios across the various scales (how will drivers change and will this affect the loads to the coastal sea?) provide preliminary assessment that sets the stage for dynamic scenario analysis.

The critical thresholds information can be derived from: ecological (State/Impact relationship) as well as political and managerial information (Response) which refers to environmental quality standards, regulations, water directives and other comparable instruments.

The following steps are taken:

Table RA1. Major coastal Impacts/issues and critical thresholds in coastal zones – Overview and qualitative ranking based on change in the region following the key questions

- What are major impacts (coastal issues) along the coastal zone?
- How close are they to a critical threshold of system functioning?

Coastal impact/issue e.g.	**Local site/region (contributing river basins) e.g.**	**Critical Threshold (for system functioning) e.g.:**	**Distance to Critical Threshold (qualitative or quantitative) e.g.:**	**Impact category (Impact code and rank of importance e.g. 1- 10)**	**References/ data source**
Erosion (coastal geomorphology)	River ABC - Delta	• For coastal stability; Sustained delivery of xy t per year • …..	Qualitative or quantitative information. about the amount needed for coastal security. (e.g., no distance since the sediment delivery due to damming has been reduced to such a level that coastal erosion becomes a continuos process)	Erosion - 10	Database xyz, Reference abcd, 19……
Eutrophication (habitat loss)	Bay ACEF – (rivers draining into the Bay a,b,c,…)	• Seagrasses show signs of destruction; • Occurrence of anoxia or low oxygen in estuaries; • Nutrient load is at the threshold.	Further increased nutrient load by 20-30% will change the system	Eutrophication - 8	
Pollution	Rivers XYZ				

<u>*Notes for use*</u>

This table is a first priority list of issues for the regional coast based on riverine (i.e. catchment-based) forcing. It serves to compile as much information as possible on critical fluxes, loads and thresholds for systems functions. It provides a first overview of a remaining capacity for material input or withdrawal that a target ecosystem might be able to handle without observable change. This can refer to a single function such as the stability of a coastal area against erosion. It can also refer to a multicausal impact affecting for example fisheries or water quality. These critical load and threshold estimates return in tables 6 and 7 as part of the "hot spot" and response assessment.

The ranking involves 4 main categories: values 1-3 no or minor importance, values 4-6 = medium importance, values 7-9 = major importance and value 10 = critical.

Table RA2. DPSI matrix characterizing major catchment-based Drivers/Pressures and a qualitative ranking of related coastal State changes Impacting the coastal zone versus **catchments size class.**
State change dimension: major; medium ; minor ; no impact; ? = insufficient information.
Time scale: p = progressive (continuous); d = discrete (spontaneous) n.a. = not applicable

Key questions and examples:

- What are the major (max. 10) driver/pressure settings on river catchment level causing coastal change?
- Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues?

Driver	**Pressures**	**State change (qualitative index)**				**Impact on the coastal system**	**Time scale**
		Large basins	**Medium basins**	**Small basins: active coast**	**Small basins: passive coast**		
Agriculture	▪ Waste/nutrient (excess fertilizer) ▪ Increasing sediment transport ▪ Water extraction	**minor**	**medium**	**major**	**major**	▪ Eutrophication; ▪ Contamination; ▪ Siltation, etc….	**p**
Damming	▪ Nutrient and sediment sequestration ▪ Changing hydrological cycles	**?**	**major**	**n.a.**	**medium**	▪ Coastal erosion; ▪ Nutrient depletion; ▪ Salinization	**d**
Deforestation	▪ Sediment budget alteration ▪ …..	**minor**	**major**	**major**	**major**	▪ Siltation; ▪ Sediment accretion/ Erosion	**p**
etc	**etc**					**etc**	

<u>*Notes for use*</u>
Please refer to the basins in your sub-region or for which you have information and make a judgement on how intense the effects of the various drivers on these catchments are and to what extent this may impact on the coastal zone. Ranking is in three categories (also used in tables 1 and 3-5); those are: minor importance equals 1-3, medium importance equals 4-6, major importance equals 7-10.
State changes in coastal zones driven by a catchment – based prozess will vary according to catchment size, for example: Deforestation even on large scale if conducted in a huge catchment such as the Amazon or Congo will cause a rather moderate if any coastal signal as compared to effects originating from pressures on small catchments where even minor deforestation can dramatically influence the sediment budget in the coastal zone. So, deforestation in the Amazon would score a "minor" while in a small catchment it could go score a "major" ranking. Where your information is referring to only one catchment type or class (e.g., large >200.000 km^2, medium 10.000 – 200.000 and small <10.000 km^2), delete or ignore the other columns.
Active/passive coast refers to geomorphology, tectonics and climate. Small rivers along the African East coast for example are in a tectonically rather passive area with high seasonality in runoff (monsoonal influence) while small rivers in other areas e.g. the South American West coast are located in a tectonical rather active area exhibiting high slopes but they also featuer high amplitiudes of seasonal runoff run off variation on a yearly time-scale. South America's East coast features passive areas and moderate run off schemes.

Table RA3. Linking coastal issues/Impacts and land based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on local or catchment scale.

Key questions:

- What are the major pressure/driver settings at catchment level causing coastal impacts?
- What are the future trends (based on hard data or expert judgement)?

Coastal Impact/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		River A	Category (1 low – 10 high)		
Erosion	Damming	• Area… • Volume… • Run off reduction… • …..	10	Increasing	XYZ, 2000
	Deforestation	• Area… • Residual TSS production… • …..	8	stable	
	Diversion	• Little, area…; effect on water flow… • …..	4	decreasing	
Erosion total	All drivers	In River A	Ranking weighted from information above	Overall trend	
		River A	Category		
Eutrophication	Agriculture	Residual nutrient production…	9		
	Mariculture	Local residual nutrient production…	5		
	Municipal waste	Local urbanisation areas… ; xy t/tear residual production	10		
Eutrophication total	All drivers	In River A	Ranking weighted from information above	Overall trend	
Further issues					
etc					

Notes for use:
After finishing River A, continue with River B,C etc. Where possible please treat pollution separately from eutrophication.
The ranking involves four main categories with values 1-3 = no or minor importance; values 4-6 = medium importance; values 7-9 = major importance and value 10 = critical.

Table RA4. Linking coastal issues/Impacts and land-based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on country or sub-regional scale;

Key questions and example:

- What are the major pressure/driver settings on country or sub-regional level causing coastal impact observed?
- What are the future trends (based on hard data or expert judgement)?

Coastal impact/issues	Drivers	*Sub-regional* **(i.e. by country or comparing open versus enclosed seas)**		Trend-expectation	References/ data sources
		Sub Region A	Category (1 low – 10 high)		
Erosion	Damming	• Catchments involved • Area… • Volume… • Run off reduction…	5	stable	
	Deforestation	• Area… • Residual TSS production…	8	increasing	
	Diversion	• Little, area…; effect on water flow…	4	increasing	
Erosion (total in sub region A)	All drivers and rivers weighted	b Region A	Ranking weighted from information above		
Eutrophication	Agriculture	Residual nutrient production…	9		
	Mariculture	Local residual nutrient production…	5		
	Municipal waste	Local urbanisation areas… ; xy t/year residual production	10		
Eutrophication (total in sub region A)					
etc.	**etc.**	**etc.**			

Notes for use:

If you have information about more than one sub-region e.g. north-west Africa or north-east Brazil, please treat them separately. Information involved here should summarize the coastal issues for the whole region and consider all the rivers reaching the coast.

The ranking involves 4 main categories: values 1-3 = no or minor importance, values 4-6 = medium importance, values 7-9 = major importance and value10 = critical.

Table RA5. Linking coastal issues/Impacts and land-based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on whole regional or continental/sub-continental scale;

Key questions:

- What are the major pressure/driver settings at whole regional, continental/sub-continental level causing coastal impact observed?
- What are the future trends (based on hard data or expert judgement)?

Coastal impact/issues	Drivers	Full regional (continent or sub-continent)		Trend-expectation	Reference/ data source
		e.g. Africa or South America	Category (1 low – 10 high)		
Erosion	Damming	• Sub-regions involved • Area… • Volume… • Runoff reduction…	2	increasing	
	Deforestation	• Area… • Residual TSS production…	8	stable	
	Diversion	• Little, area…; effect on water flow…	4	increasing	
Erosion (total in the region)	All Drivers and Rivers weighted	ll region scale	Ranking weighted from info above		
Eutrophication	Agriculture	• Residual nutrient production…	4		
	Mariculture	• Local residual nutrient production…	5		
	Municipal waste	• Local urbanisation areas… ; xy t/tear residual production	10		
Eutrophication (total in the region)					
etc.	**etc.**	**etc.**			

Notes for use:
This table should be filled in during the workshop since it will help synthesising the working group discussions on up-scaling individual catchment and sub-region based information. The ranking involves 4 main categories: values 1-3 = no or minor importance, 4-6 = medium importance, 7-9 = major importance and 10 = critical.

Table RA6. Scientific and/or management Response to coastal impact/issues in (continental region) coastal zones on catchment, sub-regional and regional scale.

Assessment of scientific and/or management Response on the various scales: overview of monitoring programmes and scientific investigations as well as (if applicable) management interventions, environmental quality standards, legislation, river and other commissions).

Key questions:

- What is the current status of response taken at scientific policy and/or management levels against the major coastal issues in the region?

River catchment	RESPONSE catchment scale		RESPONSE Sub-regional/ country scale		RESPONSE Regional scale	
	Scientific	Management	Scientific	Management	Scientific	Management
River A	e.g. monitoring programme 19--2001, Data: …; Source:	e.g. commission established; thresholds set; legislation in place… Source:	e.g. (combining catchments A-B-… Programs? Data? Source:	e.g.…	e.g. UNEP Regional Seas programme Source:	e.g. quality criteria for the regional waters? Source
River B						
River C						
River D						
River E						

<u>*Notes for users:*</u>

This table describes the current activities dealing with the issues on either a scientific or a policy level. This can include databases and monitoring efforts, local GOOS networks or simply investigations. On policy and management levels, this focus can be on guidelines, threshold values and environmental standards (political critical loads). The scale to which these measures are being applied or should apply should be mentioned.

The information and ranking of DPSIR scenarios (tables 1-5) together with this "Response" information should lead to the identification of "hot spots" to be listed in Table 7.

Table RA7. "Hot spots" of land-based coastal Impact and gaps in understanding; a first overview of issues to be addressed in future research (identifying the appropriate scale for the design of a new scientific effort).

Key questions:

- What are the major gaps in our current understanding of river catchment - coastal sea interactions?
- Which "hot spots" should be addressed in a future integrated scientific effort (natural and socio economic disciplines)

River catchment	**"Hot spot" catchment scale**		*"Hot spot" sub regional/ country scale (e.g. Maputo Bay or SADC region)*		**"Hot spot" regional scale**	
	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach
River A	…	• Biogeochemical studies • Residual calculation by economic sectors • Critical flux investigation • Stakeholder and scale analysis • ACTION • ….		e.g.…	…	…
River B						
River C						
River D						

Notes for use:

This table extracts from the regional assessment the potential demonstration sites, which can be included in a proposal for a future Regional Catchment/Coast Assessment Project - "…Cat". Ideally the sites should represent different settings which are typical for a special sub-region. This would allow up-scaling of the findings to comparable "classes" of catchment/coastal systems at a later stage. An accompanying note may be given informing about ongoing activities, link suggestions and key contact persons.

Emphasis should be on the human dimensions of catchment–coastal sea interaction considering the co-evolution of natural and societal systems (i.e. involving natural and socio-economic sciences).

Appendix II Meeting reports

AfriBasins I Workshop (contributor – O. Martins)
During the first LOICZ AfriBasins workshop, held in Nairobi 25-28 July 2000, a comprehensive scientific and institutional network was established, including representatives of GEF (Biodiversity and Land Degradation), the World Bank (African Water Resources Management Forum Interim Task Force) and UNEP/DEIA&EW and the Division of Policy Development and Law. Divided in three sub-regional working teams taking into account the heterogeneous features of North Africa, West Africa and East/Southern Africa, the network concentrated on establishing a data and information base considering the existing knowledge and the major gaps in "catchment–coastal sea" interaction issues. The DPSIR (Drivers, Pressure, States, Impacts, Response) scheme provided a practical framework facilitating the review of drivers of change at the catchment level and the identification of and first efforts to categorise key pressures on the coastal systems.

The regional assessment will continue to develop a synthesis of horizontal material fluxes, changes to African coastal zone resources and characteristic system functions, and how these link to pressures on the catchments. Where possible it will be highlighted how changes in the coastal zone may feed back on the human system. Following a classification of pressure - state scenarios as well as trend analysis on expected change, a set of indices will be developed to allow regional and finally global up-scaling of the information within the global LOICZ/BAHC typology effort.

As in other regional LOICZ-Basins meetings, the African group identified possible demonstration sites in each region with which to start the development of project proposals. The objective is to address a representative range of regional sites through interdisciplinary studies allowing for the development of indicators for sustainable use of coastal zones. Following the critical load concept, they are aimed at reflecting the human dimensions of catchment processes and coastal zone responses. The projects should be able to employ standardised assessment and modelling tools in both the biogeochemical and socio-economic fields as developed under LOICZ and build on earlier interdisciplinary efforts such as the modelling of residual productions of material fluxes as in the South East Asian project, SWOL. The proposals can be developed in consultation with other Basins projects such as EuroCat.

A major criterion for site selection is their potential for up-scaling, i.e. a set of systems that represents a reasonable coverage of "types" of DPSIR scenarios and related coastal issues allowing comparison on regional and broader scales. While valuable to the LOICZ typology effort, this approach has considerable potential for co-operation with other global IGBP projects such as BAHC, LUCC and PAGES. As well as their contribution to aspects of global change, the studies are expected to be relevant for the issues of ICAM processes in Africa.

The AfriBasins network acknowledged the holistic character of the LOICZ-Basins effort. The site studies to be developed from this context can prove valuable to complement the objectives of various ongoing or planned river-catchment initiatives. Potential for synergies was seen with activities combined under the African Water Resource Management Initiative – West & Central Africa and the Integrated Land and Water Management Action Program for Africa (initiated mainly through the implementing agencies of the GEF). For successful implementation of a continued AfriBasins in the region, it was however regarded as equally important to strive for African "ownership" of this LOICZ approach. UNEP/ROA offered to assist by providing a link to the African Ministerial Conference on the Environment, AMCEN. Through AMCEN's Water Forum and in cooperation with START, an appropriate coordination structure would be established to support the implementation of LOICZ AfriBasins as a complementing effort and to cover the various training and capacity-building needs involved. The meeting also agreed that the committee, with PASS and LOICZ, investigates potential synergies and supplementation with efforts such as IOC-ICAM and GOOS, determining how LOICZ-Basins might best complement them, and forge the appropriate links.

AfriBasins II Workshop (contributors – H. Kremer and R. Arthurton)

Opening the AfriBasins II Workshop, held in Nairobi 29 October – 1 November 2001, Mrs Rungano Karimanzira (ROA) welcomed the participants on behalf of the UNEP hosts. She stressed the importance of the Water sector to UNEP and stated her willingness to convey the workshop output to the AMCEN process. She referred to the forthcoming Johannesburg Summit meeting, noting the importance of water-related issues in the Johannesburg Action Plan.

Dr Eric Odada, representing PASS, drew attention to other major initiatives involving water including GIWA and highlighted the importance of coming to terms with the impacts of global change on water quality and availability. He noted the present lack of integrated knowledge and management between catchments and oceans, and drew attention to a need to link AfriBasins with other global science system initiatives in and around Africa.

Dr Hartwig Kremer, representing LOICZ, set the context for AfriBasins as a LOICZ core project that considered the human dimensions of land-ocean flux. The AfriBasins II workshop was building on the foundations established by the African coastal science and socio-economic community during AfriBasins I. The project focused on changes in the environmental state of the coastal zone, the receiving body for catchment processes and activities. The IGBP Open Science Meeting, held earlier this year, recognized the importance of coastal science in understanding the wider Earth System. He noted the links with IOC through the GOOS and, particularly, ICAM programmes, connecting scientific synthesis to management issues. Dr Isabelle Niang Diop spoke on behalf of IOC, drawing attention to the linkage between AfriBasins and the GOOS and ICAM programmes in Africa.

As with LOICZ-Basins projects elsewhere, standardization of the assessment using the DPSIR framework and upscaling from individual catchment to regional scales were recognized as keys to the success of AfriBasins. The aim was for AfriBasins to serve two goals. On the one hand it sought to enhance LOICZ science and thus inform the Global Change Science community; on the other, it aimed to provide a scientific basis for informing policy making and management organizations with a view to formulating appropriate response strategies. There would be an opportunity for AfriBasins to add value to GIWA, with its inventory approach to the water cascade between catchment and ocean. The output from AfriBasins would identify and prioritize cases for study under an AfriCat proposal that would be designed to examine the relationships between catchment drivers and their coastal impacts in a number of representative African catchments. The current EuroCat project would provide a model for the proposal.

Drawing on the work by the network of African scientists in AfriBasins I and attempting to fill the disciplinary and knowledge gaps identified at that workshop, AfriBasins II aimed to finalise the preliminary integrated regional assessment and to provide a link to the first global LOICZ-Basins synthesis. A state-of-the-art regional overview and an identification of "hot spots" to be picked up in a proposal for future regional integrated research were the immediate products expected from the workshop.

The AfriBasins II workshop adjusted the sub-regional divisions that had been suggested in AfriBasins I, now recognising a total of eight sub-regions (see 2.3). Using standardised *proforma* tables based on the DPSIR framework, two working groups completed the assessment compilations at catchment and sub-regional levels for the western and eastern/north-eastern coasts of Africa respectively. The emphasis throughout was on a close coupling of the physical and biogeochemical sciences with the human dimensions both of the driver-pressure settings in the catchments and of the issues and impacts at the coast. Finally the sub-regional assessments were scaled up to the regional level.

From the results of the DPSIR assessment, the workshop identified river catchments within the region that would be proposed for detailed study, examining various aspects of the driver-impact linkage. This output is aimed to feed the planned "AfriCat" proposal, envisaged as providing a conceptual umbrella covering individual study proposals, that will be developed concurrently by the AfriBasins scientists' network.

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Appendix IV Workshop agenda

AfriBasins II, UNEP Headquarters, Nairobi, 29 Oct – 1 Nov 2001

Sunday 28 October
Informal get together and briefing for the workshop – Hotel lobby 19:30

Monday 29 October

9:00 – 9:30 Registration

9:30 – 10:00 Opening Session:

Local Host – UNEP/ROA – Rugano P. Karimanzira
Pan African START secretariat, PASS – Eric Odada
UNEP – Salif Diop (Division EWA)
IGBP/LOICZ Focus 1 representative and LOICZ IPO – H. Kremer

10:00 – 11:00 Introduction (workshop background and goals)
- LOICZ-Basins, background, approach, results of other regional LOICZ-Basins activities, products, timelines and outlook
- Status and achievements of AfriBasins I
- Links to international organisations here: UNESCO'S IOC and regional

By: LOICZ/local host –*Rugano P. Karimanzira, Hartwig Kremer, Salif Diop*

11:00 – 11:15 *Coffee break*

11:15 – 12:30 1. Plenary Session
- identify chairs and rapporteurs
- regional assessment AfriBasins I; (*Sub-region Co-ordinators/LOICZ*)
- gaps and needs to refine the synthesis
- introduction to LOICZ-Basins assessment tables (background of the tables, how they have been developed). Discussion on parameterisation and ranking for upscaling and comparison of Basins information (deeper insight into the DPSIR tables, how to fill in and synthesise on various scales, subject to what has been provided to the meeting in preparation)
- discussion

12:30 – 14:00 *Lunch*

14:00 – 15:30 2. Plenary session continued
- Presentations of results of the AfriBasin II preperation (tables), executive summaries and/or personal involvement and background in LOICZ-Basins issues including **socio-economic aspects** (ca 15+5 minutes each): (Diop (also for IOC) Gordon, Kabuta (Euro/AfriCat), Nakamura (ICARM), Ochiewo, Sunday Umoh, Taljaard, Tauacale)

15:30 – 15:50 *Break*

15:50 – 16:30 Plenary session 2 continued and
- comments and additions from AfriBasins I participants invited

16:30 – 17:15 3. Plenary session – future projects
- regional LOICZ – "Cat" projects – design and goals

- AfriCat – draft and comments by participants (Forbes, Taljaard, Kremer (for Snoussi), Kabuta, Tauacala and others)

17:15 – 17:30 Plenary continued
- wrapping up
- briefing for the next day
- working groups and chairs and rapporteurs

Tuesday 30 October
"Regional Assessment of Catchment/Coast interaction and Human Dimensions"

09:00 – 09:15 1. Plenary Session – recall the last day and organisation of working groups:

09:15 – 17:00 2. Two working groups (Chairs & Rapporteurs TBA):
- on Coastal Issues, Drivers, Pressures and State/State-Changes in Africa – Filling in regional assessment tables 1-7 distributed prior to AfriBasins II, new information and ranking, refined regional synthesis and gaps along the following steps assessment tables 1-7.
- organisation of groups (along division of the coastal zone by sub-regions or coastal issues - see AfriBasins I – here e.g., a) Mediterranean Sea and Atlantic; b) East Coast).

11:45 – 12:30 brief reporting back of the groups in plenary - optional

DPSIR Assessment steps in detail (see also the attached methodology outline):
1) Assessing Issues/Impacts (and critical thresholds/loads) in the region (**Table 1**), key questions:
- What are major impacts (coastal issues) on the coastal zone and do we know anything on
- How close they are to a critical threshold of system functioning?

2) Assessment and synthesis of (max. 10) major Driver/Pressure settings generating the coastal Impact/Issues (**Table 2**), key questions:
- What are the major (max. 10) driver/pressure settings on catchment level causing coastal change?
- Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues (relative size classes of catchment basins for example)?

3) Assessment and synthesis of links between coastal issues/impacts and land based pressures and drivers on catchment, sub regional and full regional scale (**Tables 3-5**), key questions:
- What are the major pressure/driver settings on catchment level causing coastal impact observed and what are the future trends?
- What are the major pressure/driver settings on sub-regional/island or country level causing coastal impact observed and what are the future trends?
- What are the major pressure/driver settings on regional (sub-continental) level causing coastal impact observed and what are the expected future trends?
- Can we develop a first typology of catchment-coastal sea interaction in Africa and what are trend expectations for future change?

4) Assessment of scientific and/or management response on various scales, major regional "hot spots" (current or future) and gaps in understanding giving reason for further investigation in a holistic multidisciplinary scientific "AfriCat" project (**Tables 6-7**), key questions:
- What is the current status of response taken on scientific or policy/management levels against the major coastal issues in the region?
- What are the major gaps in our current understanding of river catchment - coastal sea interaction and human dimensions and which "hot spots" should we address in a future integrated scientific effort (including natural and socio-economic disciplines)?

17:00 – 17:30 3. Plenary Session on Coastal Issues, Drivers, Pressures and State/State-Changes in Africa – reporting back from the working groups

- chairs/rapporteurs report back
- revised shortlist of projects suggestions
- discussion and briefing for Wednesday

20:00 - Workshop dinner

Wednesday 31 October – "Synthesis and Future Projects"

09:00 – 09:45 1. Morning Plenary (*report by chairs and rapporteurs*)

- Recall key findings of the assessment process (the first full regional assessment results and ways ahead - drawing a qualitative and/or semi-quantitative, typological African Basins picture; key question.
- Can we develop a first issue-based rank order of catchment coastal sea interaction in Africa and what are the sub-regions involved? and
- Report back in particular on response, research needs and potential methodologies (available data) in view of human dimensions and ongoing or planned efforts, i.e. leading over to the proposal development

09:45 – 10:45 Plenary continued

- goals, design and sites for a future "AfriCat" project – Introduction and working group tasks (incl. potential templates from other implemented Basins related studies, such as EuroCat, SWOL)
- Discussion – response success and failure, types of change, pilot sites,
- Links and synergies with IOC C-GOOS and ICAM, UNEP ICARM etc.
- plenary approval on suggested sites and studies
- briefing for working groups

10:45 – 11:00 Coffee Break

11:00 – 12:302. Two working groups on "AfriCat" proposals (Chair & Rapporteur: TBA):

- evaluation of inputs to the "AfriCat" draft
- developing/refining the suggestions for demonstration project/s and drafting a first design for the local or sub-regional studies (ref. To AfriBasins I)

12:30 – 14:00 Lunch

14:00 – 15:30 3. "AfriCat" working groups continued

15:30 – 15:50 Tea break

15:50 – 16:30 4. "Africat" working groups continued:

- developing/refining the suggestions for demonstration project/s and drafting a first design for the studies

16:30 – 17:30 5. Plenary session: Reporting back and discussion

Thursday 01 November "Proposals, study design, implementation and final results"

09:00 – 09:30 1. Plenary:

- recall key results of the project development process of the last day;
- questions – suggestions - discussion

09:30 – 10:45 2. "AfriCat" working groups continued

- finish the draft of the proposal and site studies including work packages and partners
- Identify the co-ordinator person responsible for the finishing of the site studies and following up with national funding bodies (GEF on a national basis for example)

10:45 – 11:00 Coffee Break

11:00 – 12:30 3. Plenary:

- Chairs and rapporteurs to report back from the working groups and presenting of the study proposals, discussion (involve presentations from IOC, GEF and UNEP representatives and LOICZ):
- Discussion:
  - What,
  - Why (Regional and Global Relevance),
  - Where,
  - How, (incl. Structure),
  - Who, (identify co-ordinators and get commitment to finish and submit proposal/s),
  - Funding,
  - Timelines,
  - Approval on site relevant issues for participants who leave after the morning session

12:30 – 14:00 Lunch

14:00 – 15:00 4. Final Plenary with Dr Sekou Toure and Dr. H. Haidara, UNEP-ROA

- Approval of products, proposal suggestions, commitments and timelines by the plenary
- Strengthening the AfriBasins Network
- Conclusion (synthesis and proposals)
- Outlook
- Closure of the meeting

Afternoon or next day(s)- departure of participants

(key persons local and external to continue as a drafting team for the report).

Appendix V Terms of Reference

LOICZ AfriBasins II
African River Catchment/Coastal Zone Interaction and Human Dimensions
(Impacts of land -based activities on coastal seas of Africa)
UNEP headquarters, Nairobi, Kenya,
29 October – 01 November 2001

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1) Introduction - the LOICZ-Basins Background
The discussion on global change issues in coastal zones and integrated management issues increasingly recognises the interplay between river catchments and the coastal sea as of a single water continuum system. This is reflected in increasing numbers of targeted programs and key actions such as the European Water Framework Directive and UNESCO-, UNEP- and GEF-based/supported initiatives. The International Geosphere Biosphere Programme, IGBP, puts considerable emphasis on the human dimension of global change issues taking the whole water cascade as a scale. Since 1998 LOICZ contributes to the respective IGBP "water group" on various levels like the Sediment/Runoff Group (J. Syvitski) and the LOICZ-Basins core project (Wim Salomons, Hartwig Kremer). In the future of Earth system science, "water" will be the key target for a joint IGBP/WCRP/IHDP cross-cutting exercise to which LOICZ can contribute scientific assessment results generated through its regional Basins core project.

2) The LOICZ-Basins core project - Regional Assessment and Synthesis
In principle the LOICZ-Basins core project is working *inter alia* to develop a global evaluation of the importance of coastal seas as receiving bodies of land-based and naturally driven changes of horizontal material fluxes such as carbon, nitrogen and phosphorus as well as water and sediments. The scale applied to assess these pathways including groundwater is the river catchments (or whole islands, as appropriate). Priority attention is paid to the relative importance of these materials and their biogeochemical cycles as indicators representing environmental functioning and sustainable provision of goods and services under dynamic natural and human forcing. This is usually referred to as the human dimension of coastal change. Changing fluxes impacting the state of the environment and their feedback on the socio-economic system functioning are to be reviewed against the conceptual question of critical loads reaching the coastal zone and their potential to pass those thresholds beyond which systems tend to flip.

The assessment follows the DPSIR framework (adapted from "OECD core set of indicators for environmental performance review" – OECD/GD(93) 179, Paris 1993 and LOICZ R&S No. 11, 1998). It focuses on catchment based *drivers, pressures and state changes* (fluxes and material cycles) from which to derive indication of *critical loads* or distance to critical thresholds for coastal functions based on
a) political regulations,
b) environmental monitoring including historical information, and
c) stakeholder perception and requirements for coastal use (land- and sea-based).

This descriptive framework helps to sketch the various natural and social boundary conditions of systems interaction. In a mid-term perspective it may enable assessment and quantitative modelling of the effects of coastal change on delivery and use of environmental goods and services, their scientific and monetary equivalents and allow to evaluate the costs and benefits of political *response* and options.

LOICZ's commitment to global assessment of coastal change requires a serious basis for interregional and global comparison and upscaling. Regional LOICZ-Basins assessments therefore follow a standardized approach. Based on the DPSIR framework, they continue to provide qualitative or semi-quantitative ranking of catchment/island-based drivers and pressures and to reveal their relative contribution to change and impact observed in the coastal zone. This encompasses biogeochemical state parameters as well as impacts on human use. The ranking of pressures and changes in a comparable manner globally may subsequently be used for upscaling and comparison in the LOICZ typology clustering tool development. This effort is conducted in co-operation with parts of the IGBP BAHC (Biosphere Aspect of the

Hydrological Cycle) programme (see www.nioz.nl/loicz/. http://www.kgs.ukans.edu/Hexacoral/Tools/tools.htm or http://water.kgs.ukans.edu:888/public/Typpages/index.htm).

3) Links, Synergies and Futures

Within the broader context of the IGBP (current and future phases) the LOICZ-Basins project provides the scientific frame in which mid and long term collaboration with other core projects such as BAHC (Biospheric Aspects of the Hydrological Cycle), LUCC (Land Use and Cover Change) and PAGES (Past Global Changes) as well as with the IHDP and WCRP will be developed and strengthened.

With its issue-driven direction on regional and local scales, the LOICZ-Basins assessment enters the realm of coastal zone management. Engaging with users in policy and private sector advisory groups are consequent requirements for the resulting demonstration projects. An operational example on European scales can be found in the EUROCAT project http://www.iia-cnr.unical.it/EUROCAT/project.htm. This approach and its results may prove valuable to the objectives of intergovernmental organizations such as UNESCO/IOC. LOICZ therefore continues to build working relationships with the IOC's ICAM (Integrated Coastal Area Management) and C-GOOS (Coastal Global Oceans Observing System) programmes.

A global synthesising experiment such as LOICZ can thus provide global monitoring efforts and the decision-making process with relevant scientific indicators and trend analysis. In doing this it maintains a neutral platform for joint discussion aiming to generate joint ownership of issues among science and users. Examples of applied LOICZ-Basins research can be found in a Rotterdam–Rhine project dealing with forecasting of sediment quality under different catchment management and use scenarios (http://w3g.gkss.de/i_a/dredged_material/index.html).

4) Specific Workshop objectives are

1. based on the AfriBasins I interim results and the new standardised LOICZ regional assessment tables, to provide a refined state of the art report of river catchment – coastal sea interactions including the human dimensions of coastal change issues and a first ranking of key pressures and state change settings providing a data entry for upscaling purposes on regional scale (see 2);
   (this includes refinement of the regional data and information base for the first global LOICZ synthesis to be included in the synthesis book (see LOICZ newsletter No 17 – 12/2000) to be published in 2003. Regional contribution/authorship will be fully acknowledged).
2. to up-scale the information to broader sub-regional and finally regional synthesis by identifying and clustering areas of similar coastal change features using the DPSIR, framework and the ranking for classification of sites and regions (see also LOICZ-Basins regional assessment tables).
3. to confirm or reconsider the set of focussed pilot areas, for which to develop proposals for specific case studies integrating natural and socio-economic sciences aimed to elaborate on the "human dimensions" of global change along the whole water continuum (This will be based in particular on table 6 and 7 of the assessment tables).
4. to strengthen an African LOICZ-Basins network with a commitment to continue the proposal development and project co-ordination and to improve existing and seek new value-added links to other projects and organisations such as UNEP, GIWA, UNESCO-IOC (GOOS and ICAM), START and IHDP. This will be facilitated through the LOICZ platform.

5) Focus of workshop

To achieve the objectives outlined, AfriBasins II will follow the DPSIR scheme in the process of *assessment, analysis, categorisation and ranking*. The tabulated LOICZ assessment approach applied in other regional LOICZ-Basins studies and addressing a set of key questions (**See attachment: LOICZ-Basins regional assessment tables Annex II**) will be used.

Briefly, the nomenclature of DPSIR is as follows:

DRIVERS in this context are **catchment-based activities (land use and land use change)** with consequences for the coastal zone such as:

- Damming;

- River diversion and effects of irrigation and water supply activities (abstraction);
- Agriculture/urbanisation (industrial, agricultural and domestic wastes);
- Mining activities.

They cause **PRESSURES** on ecosystem and social system functioning, affecting and perhaps changing the **STATE** of the coastal environment additional to natural forcing. Following the scientific guidelines of the LOICZ global synthesising experiment:

- Water, nutrient and sediment transportation throughout the catchments are key pressure indicators for coastal change driven along the boundaries of the whole water pathway. (they should enable derivation of critical load information and ranking of observed coastal issues linked to pressures);
- The dynamics and geomorphologic settings along the catchment (retention times in the catchment) are to be considered; as are
- Economic fluxes relating to changes in resource flows from coastal systems, their value and changes in economic activity.

IMPACTS are observed effects on coastal systems showing up for instance as habitat-loss/modification, changes of biodiversity, changes of social and economic functioning and resource and service availability and use. They translate into the **COASTAL ISSUES** from which the assessment process (in Table 1) embarks. Fnally, the

RESPONSE reflecting action taken (including coastal management) to either protect against change such as eutrophication or pollution, erosion by means of reduced sediment loads or sea-level rise, ameliorate adverse effects and ensure sustainable use of resources.

6) Products and Expectations

Based on the preparatory work in Phase I, AfriBasins II is expected to lead to:

- a **LOICZ Reports & Studies (R&S) series volume** (which also forms the basis for part of the LOICZ synthesis in 2002) covering the following topics**:**
    1. Coastal impact/issues (environmental and socio economic focus)
        - 1.1 Development of qualitative indices
        - 1.2 Categorise the relevance of Impacts
    2. Drivers
    3. Pressures
        - 3.1 Development of qualitative indices
        - 3.2 Categorise the relevance of Pressures
    4. States and state-changes (Fluxes, material cycles)
    5. Response
        - 5.1 Socio-economic and political/legal settings and change
        - 5.2 Scientific and/or monitoring Response
    6. Regional up-scaling
        - 6.1 Typology development, comparing and upscaling DPSIR parameters of coastal change and scenarios by simple approximation and cluster analysis
        - 6.2 Types/classes of regional features;
    7. Trend analysis
        - 7.1 Defining Change - the "delta" of key parameters and derive a trend prediction;
    8. Gaps
        - 8.1 Data and information gaps;
        - 8.2 Efforts/commitments needed to fill these gaps;
    9. Outlook for future research (a proposal for an African catchment/coast project "Africat").

- a draft follow-up proposal aimed at cross-disciplinary (i.e. combining natural and social science) pilot studies complementing parallel developments in the other regional Basins efforts – as a template the European "EuroCat" project may be used.

(Priority for site selection is the potential for upscaling i.e. to identify areas representative for a certain type of catchment - coastal sea - driver interaction characteristic in a sub-region).

7) Workplan (tentative) and documents

- The workshop is planned for 29 October to 1 November 2001, at UNEP Headquarters, Nairobi, Kenya.
- Background documents:
  - AfriBasins I interim report (draft),
  - LOICZ R&S No 11 on Integrated Modelling and the DPSIR, available for downloaded as a pdf file from http://wwwnioz.nl/loicz/,
  - LOICZ-Basins regional assessment tables (including templates from earlier workshops in South America and East Asia as guidelines);
  - draft design for an AfriCat proposal to be completed during the workshop;
- the LOICZ (R&S) volume should be ready for publishing jointly with the partner organisations within four months after the workshop. A lead editor (to be identified) will have the responsibility for the drafting process and keeping timelines. Individual authorship of sections of the final document will be acknowledged.
- Special publications in peer-reviewed journals (e.g., Regional Environmental Change by Springer) are encouraged.
- The meeting will be asked to agree on timelines and approve the schedule and contents for/of products to be delivered.
- Pilot areas will be identified at the meeting and drafting of the proposal will be a participants' task following approval by the meeting. Commitment of task leaders to pursue the proposal development will be sought and approved and LOICZ as a platform will support and seek support from partner organisations involved in the submission process.

8) Participants

The workshop is highly product-oriented and has to be run on a tight budget. Attendance will therefore be limited to a maximum of 15 to 20 participants, including resource scientists and organisers plus technical secretarial support (preferably asked from the local organiser).

The scientists who will be approached for expression of interest are: AfriBasins I task-leaders and those researchers from Africa and elsewhere, who are exposed through their work field to issues that have not been covered adequately in Phase 1.

They are asked to fill in the tables, to comment on the proposal draft and to provide a 4-5 pages extended executive summary on their work/experience in LOICZ-Basins related work-field (if not done in Phase 1) prior to the meeting. This is a vital prerequisite to finish the regional assessment process along the key questions during the first half of the meeting and to continue with the proposal development.

Invitation and support will be based on scientific review of pre-filled tables and comments on the draft proposal design (applying to all participants) and extended executive summaries (applying to those scientists only who have not been involved in Phase 1). These documents are to be submitted to the organisers as outlined in the letter asking for expression of interest.

An invitation list will be finalised subject to expression of interest and accordance with these Terms of Reference returned to the organisers.

9) Concluding Remarks

Appropriate involvement of **socio-economic information** into the assessment and development usually turns out to be the major challenge showing biggest gaps in appropriate networking. This should therefore be a priority issue in this phase of network formation and further development. The network is strongly encouraged to identify relevant capacities in their surrounding and encourage their participation.

In the process of verifying and approving demonstration sites for future holistic project proposals along the LOICZ design emphasis will have to be on both, the up-scaling and management relevance as well as on broader contribution to global efforts. Examples are those launched through UNESCO's IOC (Integrated Coastal Area Management ICAM, Coastal Global Ocean Observation System, C-GOOS) as well as the regional efforts for synthesis and capacity building launched for example through the START network. In principle existing and/or planned regional efforts should be complemented.

Appendix VI List of important acronyms and abbreviations

ACOPS	Advisory Committee for the Protection of the Sea
AMCEN	African Ministerial Conference on the Environment
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP core project)
C-GOOS	Coastal Module of the Global Ocean Observing System (IOC)
DPSIR	Driver-Pressure-State-Impact-Response assessment framework
GEF	Global Environment Facility
GIWA	Global International Waters Assessment
GOOS	Global Ocean Observing System
ICAM	Integrated Coastal Area Management
ICARM	Integrated Coastal Area and River Basin Management
IGBP	International Geosphere Biosphere Project
IOC	Intergovernmental Oceanographic Commission of UNESCO
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP core project)
LUCC	Land-Use/Cover Change (IGBP co-sponsored core project)
NGO	Non-governmental Organisation
NORAD	Norwegian Agency for Development Cooperation
OECD	Organisation for Economic Cooperation and Development
PAGES	Past Global Changes (IGBP core project)
PASS	Pan-African START Secretariat
RIKZ	Rijksinstituut voor Kust en Zee (The Netherlands National Institute for Coast and Sea)
ROA	Regional Office for Africa (UNEP)
SADC	Southern Africa Development Council
SAmBas	South American Basins (LOICZ-Basins core project)
START	Global Change System for Analysis, Research and Training
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation