AN ASSESSMENT OF HYDROLOGICAL AND LAND USE CHARACTERISTICS AFFECTING RIVER-COAST INTERACTIONS IN THE WEST INDIAN OCEAN REGION

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Acronyms and Abbreviations

AMCEN	African Ministerial Conference on the Environment
AUF	African Unification Front
CITES	Convention on International Trade in Endangered Species
BOD	Biological Oxygen Demand
CMAs	Catchment Management Agencies
CPW	Challenge Programme on Water and Food
DO	Dissolved Oxygen
DNA	National Directorate of Water (Mozambique)
EEZ	Exclusive Economic Zone
EAC	East Africa Coastal Current
EIA	Environmental Impact Assessment
EMA	Environmental Management Agency
GIWA	Global International Water Assessments
GNP	Gross National Product
GoK	Government of Kenya
GPA	UNEP's Global Programme of Action for the Protection of the Coastal and Marine Environment from Land-based Activities
GWP	Global Water Partnership
HDI	Human Development Index
ICRI	International Coral Reef Initiative
ICARM	Integrated Coastal Area and River Basin Management
IMO	International Maritime Organisation
IWMI	International Water Management Institute
INE	National Institute of Statistics
IOC	Indian Ocean Commission
IOCINCWIO	UNESCO's Intergovernmental Oceanographic Commission's Regional Committee for Cooperative Investigations in the North and Central Western Indian Ocean
IOMAC	Indian Ocean Marine Affairs Commission
IUCN	International Union for Conservation of Nature
ITCZ	Inter-tropical Convergence Zone
JIBS	Joint Incomati Basin Study
LIMCOM	Limpopo River Basin Commission
LMEs	Large Marine Ecosystems
LRB	Limpopo River Basin
MAR	Mean Annual Runoff
MAP	Mean Annual Precipitation

NEMC	National Environmental Management Council
NEMP	National Environmental Programme
NLUC	National Land Use Committee
NWC	National Water Commission
NYM	Nyumba ya Mungu Dam in Pangani River Basin, Tanzania
PADH	Physical Alteration and Destruction of Habitats
PBWO	Pangani Basin Water Office
PIBO	Pacfish/Infish Biological Opinion
RBMIIP	River Basin Management Improved Irrigation Project
RBO	River Basin Organisation
RSA	Republic of South Africa
RSAP-IWRM	Regional Strategic Action Plan on Integrated Water Resources Development and Management
RWAs	Regional Water Authorities
SADC	Southern African Development Community
SARDC	Southern African Documentation and Research Centre
SAP	Strategic Action Programme
SEA	Strategic Environmental Assessment
SMUWC	Sustainable management of the Usanga Wetlands and Catchment
TARDA	Tana and Athi Rivers Development Authority
TANESCO	Tanzania Electric Supply Company
TDA	Transboundary Diagnostic Analysis
TDS	Total Dissolved Solids
TIA	Tripartite Interim Agreement
TPTC	Tripartite Permanent Technical Committee
TSS	Total Suspended Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNOPS	United Nations Office for Project Services
UNCLOS	United Nations Convention on the Law of the Sea
WIO	Western Indian Ocean
WSSP	Water Sector Support Programme
WUAs	Water Users Associations
ZAMCOM	Zambezi River Basin Commission
ZRA	Zambezi River Authority

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Executive Summary

This report presents an assessment of hydrological and land use characteristics affecting river-coast interactions in the West Indian Ocean region. One of the key areas of concern for the WIO region relates to the interaction between river basins and the coastal and marine environment. The report provides an overview of the characteristics of the main rivers flowing into the South-West Indian Ocean, from Kenya, Tanzania, Mozambique, South Africa and Madagascar incorporating hydrology, land use and environmental issues.

Physical description of the WIO region

The WIO region has a combined coastline exceeding 15,000 km (including those of the island states) and a total continental shelf area of about 450,000 km^2. The region is characterized by a wide diversity of habitats including sandy beaches, sand dunes, coral reefs, estuarine systems, mangroves, sea grass beds. The climate in the region can be characterised as tropical and sub-tropical with temperatures in the northern parts ranging between 24^{o}C-30^{o}C while the hottest summer reaches 34^{o}C, usually recorded in the months of December through February. This climate can be characterised by two distinct prevailing wind regimes: the monsoon regime, which strongly influences the region's rainfall seasons and the subtropical high-pressure system. The rainfall seasons in the WIO are strongly influenced by monsoon winds. The northern part of Mozambique, Tanzania, Kenya and the southern parts of Somalia receive long rains in the period March through May, before the Southeast Monsoon sets in while short rains are experienced in October through December during the Northeast Monsoon. The WIO region is drained by twelve major river basins that flow into the Indian Ocean. Many of the rivers terminate with important estuaries or deltas that serve as habitat and rich breeding grounds for various species of fish, crustaceans and other marine life.

WIO region Governance Framework

There are two main international conventions of United Nations Convention on the Law of the Sea (UNCLOS) and the Nairobi Convention. All ten countries that are parties to the Nairobi Convention are also parties to the 1982 UNCLOS. The UNCLOS sets the framework to encourage governments to address the impacts on the marine environment from land-based sources and activities. The management of international watercourses through regional cooperation provides the most comprehensive basis for environmental protection and pollution control. Shared water agreements are flexible in nature but provide broadly for two categories of shared watercourse institutions:

- Shared Water Commissions that are essentially advisory bodies providing a forum for notification, consultation and negotiation, for coordinating responses to

emergencies, for collecting data, and environmental matters including setting water quality targets and standards
- River Basin Authorities go further in that they have specific powers granted to them by parties to the shared waters agreement concerned.

Besides, there are five important 'soft' laws that have been established over the last twenty years that are relevant to the WIO region; namely Agenda 21, Montreal guidelines, Washington Declaration and Global Programme of Action (GPA) on Protection of the Marine Environment from Land-Based Activities (GPA), World Summit on Sustainable Development and Johannesburg Plan of Implementation, and UNEP's Regional Seas Programme. Each one of the WIO countries has one or more national government institution for the environment and/or natural resource management.

Land use and Water demand

Even though countries within the WIO region are in different stages of economic and social development, land-based sources of marine pollution in the region are primarily associated with densely populated areas and industrial zones within urban centres and in the vicinity of river discharges, particularly those from larger river basins. Of increasing concern in the countries of the WIO region is the rapid and often uncontrolled urbanization (including tourism developments) occurring in coastal areas. Associated with this rapid and uncontrolled urbanisation are severe increases in municipal wastewater, municipal solid waste and atmospheric emissions (e.g. from fossil fuel burning and vehicular traffic) which are often not properly managed or controlled, thereby contributing to many of the priority transboundary marine pollution problems seen in the region

Agriculture is the backbone of the economy of most countries in the WIO region and is central to the alleviation of poverty and generation of revenue. Agricultural activities contribute mainly to marine pollution particularly practices that produce elevated levels of four types of pollutant, namely suspended solids (the result of erosion due to inappropriate land use practices), inorganic nutrients (excessive use of fertilizers), pesticides (persistent organic pollutants) and microbial contaminants (typically associated with runoff from livestock rearing areas). Pollutants from agricultural activities usually enter the marine environment through river discharges, although agricultural activities adjacent to coastal areas can directly contaminate coastal waters through surface or sub-surface runoff.

Mining is another mainstay of economic development in much of the region. Although precautions are generally taken to ensure that environmental impacts from mining activities are minimised, there exists the potential for the contamination of water resources from mine water runoff. This has already become an issue in the Limpopo Basin, in the headwaters of the Limpopo River, where acid mine drainage from decommissioned gold mines on the Witwatersrand has found its way into groundwater (Coetzee *et al.* 2005). In addition to large-scale mining activities, in several regional basins there are small-scale, unregulated or illegal, mining activities. These lead to erosion of river banks during excavation, digging and panning processes, increasing the sediment load and turbidity of rivers. Multiple numbers of these on a single river course can result in significant and detrimental effects in the lower reaches of basins, irreversibly altering the natural ecological goods and services provided by river outflow areas.

The transportation sector has impacted on river basins in areas where road networks have been covered with impermeable surfaces. This reduces water infiltration to top soils leading to increased runoff and flash floods, causing soil erosion in adjacent non-hardened areas and thus an increase in sediment loads. Conversely, non-hardened or dirt roads, through the clearing of natural vegetation to expose bare soil for their construction and long-term use, may also increase soil erosion during rain events.

Several countries in the region rely extensively on energy produced by hydro-electric power schemes – important for Kenya, Tanzania and Mozambique. Much like dams constructed for water-supply, these hydro-power dams alter the flow regime of rivers and trap sediments. The Cahora Bassa Dam on the Zambezi River has had an impact on its delta, many hundreds of kilometers away by encouraging coastal erosion and reducing the nutrient supply carried downstream by floods (Turpie 2006, Brown and King 2002). In South Africa, large amounts of water are taken from rivers for wet cooling of thermal power stations, impacting particularly the Limpopo and Incomati rivers once the warmed effluent is returned to the rivers.

Environmental Issues

The specific environmental impacts are many and varied. There is some evidence of the impact associated with nutrient enrichment from land-based activities with the problem mainly confined to more sheltered environments such as estuaries and creeks where weak water circulation generally limits the environment's assimilative capacity for nutrient and biodegradable organic matter. However, with the rapid increase in coastal urbanisation (and associated municipals waste), as well as the projected increase in commercial agricultural and expansion of industrial activities in the region, nutrient loads to the marine environment could increase markedly over the next years, challenging the assimilative capacity of coastal regions.

Seven common factors contribute to environmental problems related to river-coast interaction in the WIO region:

- *Climate change and natural processes* – Climate change and natural events to an important extent influence river flows, turbidity and sediment transport. Most of the region is characterised by large spatial as well as temporal variations in rainfall. Climatic changes are likely to include an increase in extreme events such as floods and droughts following on from each other thereby increasing the stress on already compromised river systems in the region by increasing soil erosion and sedimentation and, in places, increasing pollution concentrations where average water volumes decline. Reduced freshwater volumes to the coast in times of drought poses a considerable threat to river-coastal processes.
- *Economic growth* - Increased demands for limited water resources due to economic growth in the region results in growing competition over the resource between different sectors and the construction of more dams on rivers. Over the past half century, countries in the WIO region have experienced high levels of economic development, with a commensurate increase in water use in river basins for industry, mining, urban development, agriculture and energy production.
- *Population pressure* – The increased demand for water resources by growing populations can change river systems, irreversibly. For example, in the Pangani River basin. All of the countries in the region have experienced medium to high rates of overall population growth, which in the context of a finite supply of water resources, equates to a greater demands on existing supplies.
- *Poverty and inequality* – Due to limited resources, people engage in unsustainable land-use practices, such as over-stocking of cattle leading to over-grazing and therefore increased runoff of nutrients and soil erosion.
- *Inappropriate governance* - The lack of inter-sectoral coordination, notably with little or no involvement of different water use sectors, with different sets of requirements in the management of the resource, leads to the misuse of the resource. The lack of information and data (in some areas) of the nature, causes and impacts of environmental problems, and weakly enforced legislation, compounded by the lack of harmonised legal and institutional frameworks for the management of transboundary rivers has caused the deterioration of rivers and adjacent coastal areas.
- *Inadequate knowledge and awareness* – Includes two important factors:
  - Shortcomings in information and data of the nature, causes and impacts of certain environmental problems.
  - Lack of awareness of stakeholders of the impact of their activities on other stakeholders and the ecosystem as a whole.

- *Inadequate financial resources* and human capital– There is limited financial and human resource capacity for effective implementation and monitoring of agreements and comprehensive water management regimes.

The impacts on the coastal and marine environment of changes in river flow and sediment load from rivers offloads on the WIO, coastal and marine environment results in physical alteration and destruction of habitats, the degeneration of water quality or a combination of these issues.

The main sectors contributing to the environmental problems in the WIO region are:

- Urbanisation and Coastal Development – Population growth is a fundamental component, accompanied by changes in settlement patterns from rural to urban environments and related coastal developments. Apart from the communities themselves, specific sectors involved are property developers, town planners, operators of wastewater management facilities and solid waste operators.
- Physical alteration and destruction of habitats (through removal of vegetation cover) - Major small-scale stakeholders include firewood collectors and charcoal burners, farmers, loggers, pastoralists and bee keepers.
- Industry – Involves both small and large scale industries based in the coastal zone. These include agro-processing industries, manufacturing industry, oil-refineries and desalination plants.
- Mining – This range from coral/lime miners, sand miners, salt work producers (both small scale and industrial).
- Tourism – Encompasses hotels, tourists, tour operators and small-scale traders involved in tourism activities at the coast.
- Energy production – This sector concerns (hydro-) power stations, renewable energy producers and fossil fuel user

An observed but less studied phenomenon is reduced stream flows increased sedimentation (due to catchment degradation) and impoundments. The need to address the issue has been highlighted in recent years by the concept of environmental flow requirements.

1. Introduction

One of the key areas of concern for the WIO region relates to the interaction between river basins and the coastal and marine environment. According to the TDA study that was conducted for the area, a common problem in the WIO region is poor land use practices (e.g. over-grazing, deforestation) which are often aggravated by increased population pressure. Poor land use practices can lead to problems of large-scale soil erosion (and resulting increase in sediment load), which may severely impact river floodplains. Combined with reduced or significantly altered flows, detrimental effects can be felt at the estuaries (Dunne and Ongwenyi 1976, Kitheka *et al.* 2004a, Turpie 2006). Natural phenomena such as climatic extremes (violent rainfall) coupled with slash-and-burn practices to clear land for grazing is a common cause of wide-scale soil erosion.

Coastal areas are the interface of land and marine ecosystems. Their extent is defined on the basis of functional interaction between natural and human ecosystems on both sides (landward and seaward) of the coastline or the inter-tidal zone. River basins are also important areas from the point of view of natural ecosystems particularly on the basis of the presence of water and its support for the flora and fauna in the area. Coastal areas and river basins can be considered as similar from the perspective of the structure of the basic feature of the land/water interface which is important for both natural and human ecosystems. The availability of resources attracts human activities, particularly the presence of water as an essential input or a course for transport and a potential recipient for waste. As a result there might be similarities in terms of environmental pressures on water (the sea), soil, vegetation, land and other ecosystem components. Such similarities suggest similar frameworks for rational management focusing on protecting the function of natural ecosystems, allocating resources for human use, controlling wastes.

Much of the population in the WIO region, especially in the hinterland of the upper-reaches of the basins in the study, is heavily dependant on agriculture and forestry. These activities are associated with heavy water consumption – both through interception of rainfall (thus leading to a drop in groundwater levels) and through the evapotranspiration of irrigation water. Intense or inappropriate farming techniques, such as planting on steep slopes or deep drainage furrows, can also lead to increased erosion with sediments reaching the main flow of the river.

Experience with human interventions in such dynamic systems made it necessary to extend the scope and area of intervention to entire river basins or extending on both sides of the coastline. Such efforts were still focused over a single purpose, for example, managing water resources or marine resources. Human intervention in both rivers and coasts became increasingly multi-sectoral covering a range of economic and social goals based on a rationale of better exploitation of natural resources for human needs. The conflicting demands on natural resources brought the need for a comprehensive approach to the management of rivers and coasts introducing multiple objectives and bringing the necessity for a broader (in terms of geographic area) scope. The emphasis on the protection of the environment shifted the objective focus from resource management to ecosystem management. This integrated perspective considers rivers and coasts as dynamic systems consisting of interacting natural and human ecosystems which require rational management.

Within this context, the focus of this analysis is on land-based sources of marine pollution as opposed to pollution linked to maritime transportation or dumping of waste at sea. Land-based sources of marine pollution in the WIO region are primarily associated with densely populated areas and industrial zones within urban centres and in the vicinity of river discharges, particularly those from larger river basins. The main basis and justifying data for the analysis presented in this report is a number of targeted studies commissioned by the Nairobi Convention, largely as part of the WIO-LaB project which resulted in a series of supporting documents.

1.1 Scope of Study

The main objective of the study was to develop an overview of the characteristics of the main rivers flowing into the South-West Indian Ocean from Kenya, Tanzania, Mozambique, South Africa and Madagascar incorporating hydrology, land use and environmental issues. Specifically the study aimed to:

1. Compile data for the main rivers flowing into the South-West Indian Ocean (WIO) from the countries concerned (the final list of rivers include, but is not limited to, the Shebelle, Tana, Sabaki, Pangani, Rufiji, Ruvuma, Zambezi, Save, Buzi, Limpopo, Incomati and Betsiboka)
2. Describe hydrological conditions in the basins, covering runoff, mean annual rainfall, flow regime and sediment transport
3. Describe factors which may have an impact on this hydrological situation, including but not limited to, climatic variability and change, demographic change, economic development (national and local), agriculture, water abstraction and the construction of water infrastructure such as dams
4. Assess the current and future environmental threats – related to water quantity, water quality and sediment load

5. Describe the governance institutions (legislation, agreements, protocols and river basin organisations) relevant to the management of the river basins (national and regional) listing key provisions, roles and degree of implementation.

1.2 Limitations of the Study

A number of constraints were encountered during preparation of the report. First, the scope and quality of data varied from country to country and basin to basin. It was difficult in some cases to make comparisons across basins and countries. Second, there was scarcity of information and absence of data in some cases. To some extent the evidence presented in this report can be considered anecdotal. Third, there were few comprehensive studies and this resulted in gaps in the data.

1.3 Structure of the Report

Chapter 2 provides an overview of climate and the main hydrology of the basins. This is followed in chapter 3 by a description of the various land uses and the consequent water demand. In chapter 4 is a discussion on environmental issues covering the main threats. This report should be understood as an input into the Rivers Overview Report for the WIO-LaB Transboundary Diagnostic (TDA) Report.

2. Description of the WIO Region

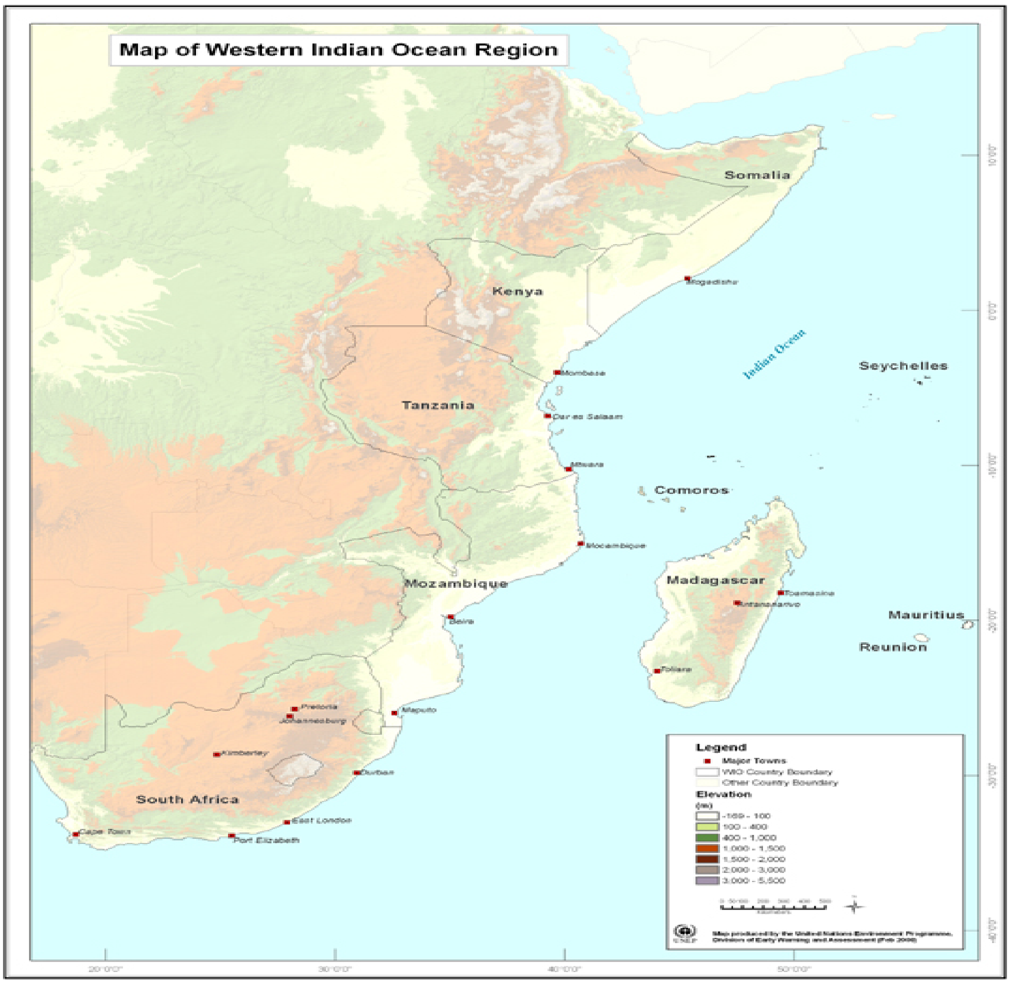
2.1 Overview

This section presents an overview of the WIO region- the physical characteristics including geographical location, climate[1], and hydrology. The international, regional and basin governance framework and institutions managing the region also form part of the section.

2.2 Region Description

The WIO region has a combined coastline exceeding 15,000 km (including those of the island states) and a total continental shelf area of about 450,000 km^2 (GEO 2003) as detailed in Table 2.1 and Figure 2.1.

Figure 2.1: Map of the West Indian Ocean Region



[1] This overview of the climate is drawn from UNEP 2004.

The region is characterized by a wide diversity of habitats including sandy beaches, sand dunes, coral reefs, estuarine systems, mangroves and seagrass beds. The region also has several major river basins that drain into the Indian Ocean (Van den Bosche and Bernacsek 1990, Hatziolos *et al.* 1996, Hirji *et al.* 1996, FAO 2001, UNEP 2001). Some of the coastal-marine ecosystems and river basins are transboundary in nature as they extend across more than one country.

Table 2.1 Key geographical characteristics of the WIO region countries

Countries	Land area (km^2)	Coastline (km)	Territorial waters (km^2)	Continental Shelf (km^2)	EEZ (million km^2)
Comoros	2,230	340	12,684	1,416	0.161
Madagascar	581,540	4,828	124,938	96,653	1.079
Mauritius	2,030	322	16,840	27,373	1.274
Seychelles	450	491	45,411	31,479	1.288
Kenya	569,140	536	12,832	8,460	0.104
Mozambique	784,090	2,470	70,894	73,300	0.493
Somalia	62,734	3,025	68,849	40,392	1.200
South Africa	1,214,470	2,881	74,699	160,938	1.016
Tanzania	883,590	1,424	36,578	17,903	0.204
TOTAL	**4,100,274**	**15,141**	**463,725**	**457,914**	**6.819**

Data extracted from the GEO Data Portal 2003

2.3 The Climate

The climate in the WIO region can be characterised as tropical and sub-tropical. Temperatures in the northern parts range from 24°C-30°C while the hottest summer reaches 34°C, usually recorded in the months of December through February. In Kenya, the temperature range between summer and winter is the smallest (range from 25°C to 30°C). In Tanzania and northern Mozambique, the temperature range between 21°C and 33°C. The relatively lower temperatures, ranging between 4-14°C are usually experienced in the period June through August in the southern extreme of the region. Temperature ranges in South Africa, for example, are around 27°C in summer with a maximum of 34°C during the winter months (AFRISCO 1994, IUCN 2003, FAO 2005).

The prevailing wind regimes in the WIO region can be divided into two distinct systems: the monsoon regime that dominates the Somali Current Large Marine Ecosystem (SCLME), and the subtropical high-pressure system that dominates the southern part (the Agulhas Current

LME, or ACLME). The Northeast Monsoon affects the climate of the northwest Indian Ocean from December to April and is characterized by north-easterly winds over the tropics and northern subtropics. The Northeast Monsoon has winds of moderate strength, with dry terrestrially-derived air and wind directions from Arabia to Madagascar. In contrast, during the months of June to October, the Southwest Monsoon reverses the wind direction and the winds then tend to be much stronger, with an intense wind jet developing along the high Eastern African highlands (Ethiopian highlands, Kenya highlands, highlands of northern and southern Tanzania etc).

The rainfall patterns in the region decreases northwards from Mozambique (mean annual rainfall in the range of 530-1,140mm) to Somalia (250-375mm) and increasing inland and at higher altitudes (AFRISCO 1994, IUCN 2003, FAO 2005). On average, the island states receive more rainfall than the mainland states of eastern and southern Africa. For instance, along the west coast of Madagascar, the mean annual rainfall is in the range of 800 to 1,800 mm while the east coast receives annual rainfall ranging between 2,500 and 3,500mm. The mean annual rainfall in Seychelles, Mauritius and Comoros is in the range of 1,000 to 2,100mm. On the other hand, in the coastal regions of continental states such as South Africa, Mozambique, Tanzania and Kenya, the maximum mean annual rainfall does not exceed 1,500mm and in most cases is in the range of 500 to 1,000 mm.

The rainfall seasons in the WIO are strongly influenced by monsoon winds. The northern part of Mozambique, Tanzania, Kenya and the southern parts of Somalia receives long rains in the period March through May, before the Southeast Monsoon sets in. In the same region, short rains are experienced in October through December during the Northeast Monsoon (AFRISCO 1997, Kitheka *et al.* 2004). The islands of the Seychelles receive long rains during the Northeast Monsoon, while the rainfall pattern in other island states is strongly influenced by the Southeast Monsoon. Because of its large size, the island of Madagascar experiences climatic conditions similar to mainland Africa.

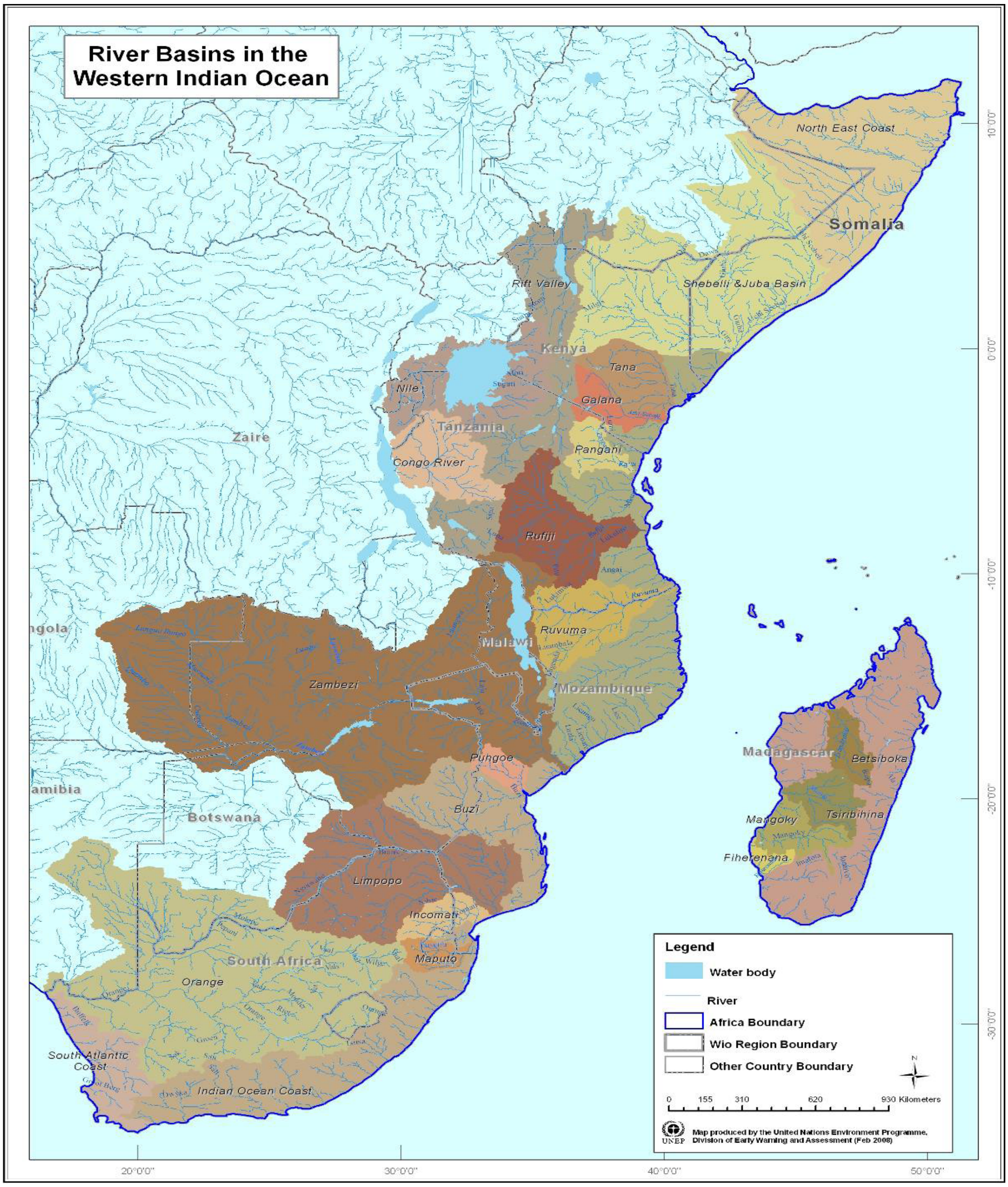
The volume of river discharge into the Indian Ocean to a certain extent reflects the rainfall patterns in the region, thus rivers draining high rainfall areas have relatively higher discharges. In the northern parts of the WIO region (e.g. Somalia and Kenya) the total annual river discharge has been estimated to be in the range of 1.8 to 4.95 km^3/yr. In the central and southern parts (e.g. Tanzania, Mozambique and South Africa) the annual river discharge is in the range of 2.9 to 106 km^3 (Hatziolos *et al*. 1996, Hirji *et al*. 1996, FAO 2001, UNEP 2001). Consequently, the southern parts of the WIO region (in particular Mozambique) are characterized by the presence of large estuarine zones supporting extensive mangrove forests.

Ocean currents strongly influence local climate. The South Equatorial Current is the principal current flowing from east to west all year around. A part of the current branches off northeast of Madagascar to form the south-eastward Madagascar Current. The main stream splits west of the northern tip of Madagascar into a southward current, which flows through Mozambique forming the perennial Mozambique Current. The northward component forms the East African Coastal Current (EACC). The EACC flows as far north as southern Somalia, after which it becomes the Somali Current. It later joins the Indian Monsoon Current during the southeast monsoon. During the northeast monsoon it becomes the eastward flowing Equatorial Counter Current. South of Madagascar, the East Madagascar Current and the Mozambique Current join at about 26 degree latitude to form the Agulhas Current. On the basis of current systems prevailing in the region, three Large Marine Ecosystems (LMEs) can be identified, namely the Somali Coastal Current, the Agulhas Current, and the Mascarene Plateau. These LMEs cover ecosystems and resources shared by several countries and extend beyond the boundaries of some of the EEZs countries.

2.4 The Hydrology

Within the WIO region there are 12 main river basins, including the largest in Madagascar. The freshwater flows from the various rivers have a profound effect on the marine ecosystems in the region, driving various ecological processes and providing nutrients for the development of species (Kairu and Nyandwi 2000, Crossland *et al*. 2005). Major rivers from the central highlands including the Maputo, Incomati, Limpopo, Save, Tana, Athi-Sabaki, Rufiji, Zambezi and Ruvuma discharge large volumes of siliclastic sediment to the sea (Kairu and Nyandwi 2000). Many of the rivers terminate with important estuaries or deltas that serve as habitat and rich breeding grounds for various species of fish, crustaceans and other marine life. Figure 2.2 shows the main river basins in the WIO region.

Figure 2.2: Map of main river basins in the WIO region



Source: UNEP-GEF WIO-LaB TDA Report 2008

Table 2.2 provides an overview of the size of the river basins, length of the main stem of the river, mean annual precipitation (MAP) and mean annual runoff (MAR), the months of the highest and the lowest flows respectively, as well as the sediment load transported to the river mouth. As can be seen there is considerable spatial variation in all of these factors. Detailed description of each of the river basin follows.

Table 2.2 Overview of the main rivers in the WIO region

River and countries	Area (km^2)	Length (km)	MAP[2] (mm)	MAR[3] (mm)	Ave flow (mm^3/y)	Highest flow month	Lowest flow Month	Sediment Load (mil. t/yr)
Tana	126,828 [a]	1,102 [b]	566 [a,c]	38 [a]	7,200 [d]	May [d]	Aug [d]	6.8 [a]
Athi-Sabaki	69,930 [e] 66,800 [f]	650 [g]	585 [a]	35 [h]	2,302 [a] 1,539 [f]	April [f]	Sept [i,f]	5.7 [a] 7.5-14.3 [i,j]
Pangani	43,650 [k]	432 [k]	1,079 [k,l]	20 [m]	850 [m]	May [m]	Sept [m]	No data
Rufiji	177,000	±600	1,000	No data	35,000 [n] 30,000 [o]	April [p,o]	Nov [p,o]	16.5 [n]; 15-25 [o]; 17 [q]
Ruvumaz	155,400 [p,r]	800 [p,s]	1,160 [s]	96 [t]	28,000 [t,u]	Feb [t]	Aug [t]	No data
Zambezi	1,300,000 [s] 1,200,000 [t]	2,650 [s]	1,000 [x]	67 [t] 190 [v]	106,000 [t]	Feb [t]	Sept [t]	43 [q] 22 [v]
Pungwe	31,000 [w] 29,500 [t]	395 [w]	1,100 [w]	115 [t]	6,600 [t]	Feb [w]	Oct [w]	No data
Limpopo	415,500 [y] 412,000 [t]	1,750 [z]	530 [iv]	13 [t]	5,200 [t]	Feb [z]	Sep [z]	10 [z] 34 [q]
Incomati	46,800 [ii,iii]	480 [s]	736 [ii]	46 [t]	3,587 [ii]	Feb [v]	Sep [v]	7 [ii]
Maputo	28,500 [t]	380 [t]	630 [t]	102 [t]	2,900 [t]	Feb [t]	Sept [t]	
Thukela	30,000 [vi]	405 [viii]	840 [vii]	133 [vii]	3,800 [vi] 4,600 [viii]	Feb [vii]	Sept [vii]	9.3 [vi] 10.5 [q]
Betsiboka	49,000 [ix]	525 [ix]				Feb [x]	Sept [x]	

Sources: a. Kitheka *et al*. 2004a b. Kitheka *et al*. 2003 c. GOK 1979 d. Kitheka *et al*. 2004b e. Kitheka *et al*. 2004d f. Fleitmann *et al*. 2007 g. UNEP 1998 h. Kitheka *et al*. 2004c i. Van Katwijk *et al*. 1993 j. Watermeyer *et al*. 1981 k. PBWO/IUCN 2007 l. Røhr *et al*. 2002 m. PBWO/IUCN 2006a n. Temple & Sundborg 1973 o. Shaghude 2004 citing Euroconsult 1980 p. Anon Tanzania 2006 q. Arthurton *et al*. 2002 r. GoT 2006 s. Pallet 1997 t. DNA 1994 u. Kaponda 2005 v. Hirji *et al*. 2002 w. Van der Zaag 2000 x. FAO 1997 y. CP 2004 z. Louw & Gichuki 2003 ii. TPTC 2001 iii. Hoguane 2007 iv. UNEP 2005 v. Van der Zaag & Carmo Vaz 2003 vi. DWAF 2004a vii. DWAF 2004b viii. Forbes *et al*. 2002 ix. Shahin 2003 x. IWMI 2006.

Tana River Basin

The Tana River Basin is approximately 132,000 km^2 in size, which is equivalent to about 23% of the total area of the Republic of Kenya (Kitheka et al. 2004). Its annual discharge represents 32% of the total river runoff in Kenya. The river supplies 50% of the total river discharge of Kenyan rivers draining into the Ocean. The main catchment area is on Mount Kenya (5,199m asl) and the Aberdare Ranges in the Central Highlands of Kenya. The snow-covered peaks of Mount Kenya and Seven Folks reservoirs serve to replenish water in the river system.

[2] MAP: Mean Annual Precipitation
[3] MAR: Mean annual Runoff

The total length of Tana River is about 1,102 km, from its headwaters in Central Kenya Highlands to the Indian Ocean (Kitheka, Obiero and Ntenge 2003). The Upper Tana Basin in Central Kenya covers an area of 7,950 km^2, which is about 6% of the total basin area and yet contributes more than 70% of the river runoff (Schneider 2000). The Upper Tana Basin is basically dominated by volcanic rock formations. However, in the middle and lower regions, deposits of Quaternary sediments dominate and Pleistocene sands are found in a small belt along the coast.

Long-term river discharge data shows large fluctuations in river flow due to high rainfall variability. There are two periods of relatively high river discharge (when it is above 150 m^3s^{-1}), namely April-June during the South-East Monsoon and the November-January during the North-East monsoon. This corresponds to the long and short rain seasons respectively (Crossland 2005). The discharge of the river follows rainfall pattern in Central Kenya with a phase lag of about one month between peak rainfall during the South-East monsoon in Central Kenya and the corresponding peak river discharge in the Lower Tana (Kitheka et al. 2003). There is however, no phase lag during the North-East monsoon. The peak river discharges (250-750 m^3s^{-1}) in the lower Tana corresponds to peak rainfall experienced within the coastal belt. However surface runoff generated during this period does not contribute significantly to the flow of the river. The river discharges during the South-East monsoon are in general much higher than those during the North-East monsoon. The discharges show significant inter-annual variabilities associated with climatic variabilities (Kitheka et al. 2003).

Dams found in the Tana River are mainly for hydro-electric power generation (WRI 2007). The dams operated by Tana and Athi Rivers Development Authority (TARDA) were created in 1974, but the hydropower generation plants within the dams are operated by Kenya Electricity Generating Company (KenGen). TARDA’s responsibilities include developing long-range plans for effective utilization of water resources as well as coordinating and monitoring all development projects in the catchment. Table 2.3 shows characteristics of existing and potential reservoirs in the Tana basin. In Kenya increased damming and abstraction of water has led to reduced peak flow flood events downstream, major reductions in annual sediment discharge to the sea and changes in the mean river discharge rates.

In Kenya, there has been a programme of damming on the upper reaches of the Tana River since the 1960s. Power generated from the hydro-stations forms 78% of the total electricity output in Kenya. Out of this, 65% is produced in the Seven Folk Schemes (Masinga, Kamburu, Gitaru, Kindaruma and Kiambere power stations). The total installed capacity in Kenya is 598.5 MW of which 458.4 MW comes from the five Seven Folk dams.

Table 2:3 Characteristics of existing and potential reservoirs in the Tana basin, Kenya

Reservoir	Gross volume (10^6 m^3)	Surface area (km^2)	Catchment area (km^2)	Mean river discharge (m^3s^{-1})	Year of completion
Masinga*	1,560	113	7,335	97.2	1981
Kamburu*	147	15	9,520	149.5	1975
Gitaru*	20	3.1	9,520	120.9	1978
Kindaruma*	16	2.4	9,807	155.9	1968
Kiambere*	315	13	11,975	121.8	1988
Karura	74	8			Planned
Mutonga	1,580	46			Planned
Grand Falls	3,600	119			Planned
Usueni	330	26			Planned
Adamson's Falls	1,730	102			Planned
Kora Hills	3,800	190			Planned

Source: Snoussi et al. (n.d) * One of the Seven Folk Scheme dams

Sediment load has declined due to damming in the Upper Tana Basin. The rate of sediment discharge has dropped from 1950's rate of 12 x 10^6 tons.yr^{-1} to the present value of 6.8 x 10^6 tons.yr^{-1} with further decline expected (to less than 4 x 10^6 tons.yr^{-1}) if large dams are constructed at Grand Falls, Mutonga, Adamson Falls, Kora Falls and Usueni (GOK 1994). The most important factor that regulates the sediment load of the Tana river is the variability in river discharge, which in turn is controlled by variability of rainfall in the catchment areas.

Athi-Sabaki River Basin

Athi-Sabaki River basin has a basin surface area of 69,930 km^2 which makes it the fourth largest drainage system in Kenya. Within it are found large urban centres such as Nairobi (UNEP 1998, Kitheka et al. 2004d). The main catchment areas of the river are found in the Central Kenya highlands. There are two main tributaries namely Tsavo and Athi Rivers, which joins to form Sabaki River in the lower region of the basin.

The two major periods of high river discharges are related to the two monsoon-influenced short and long rainy seasons respectively. High river discharges occur May-June during the Southeast monsoon, as well as between October-December during the Northeast monsoon. During the Southeast monsoon, peak river discharge ranges 380- 600 m^3s^{-1} while those measured during the northeast monsoon ranges from 60-80 m^3s^{-1}. The low river discharges are recorded between July and August during the Southeast monsoon and between February and April during the Northeast monsoon (Kitheka et al. 2004). Peak rainfall in the upper Athi catchment usually occurs in April, showing no phase lag between peak river discharge at Malindi and peak rainfall in Central Kenya (Kitheka et al. 2004). In the lower Sabaki basin, the river breaks its banks when the river discharge rises above 350 m^3s^{-1}. The river is usually fast flowing with velocities ranging 0.30 to 1.5 ms^{-1}. Flow velocities during periods of high flow are usually above 1 $ms^{-1.}$ During low flows, the river flow velocities are reduced to less than 0.5 ms^{-1}. High flows greater than 100 m^3s^{-1} have low frequency of occurrence less than 10% while low discharges less than 70 m^3s^{-1} have a high frequency of occurrence greater than 80% (Kitheka et al. 2004). The flow is characterized by large seasonal variations. For example during the 2001-2004, the flow fluctuates from the low flow of 7 $m^3.s^{-1}$ to the peak flow of 650 $m^3.s^{-1}$. Mean river discharge is of the order of 70 m^3s^{-1} (Kitheka, et al. 2004).

The Sabaki estuary is one of Kenya's main drainage areas. It is 2.5 km long and has a surface area of 0.58 km^2 and is characterized by heavy sediment deposition and transport, both along the coast and within the estuary (Kitheka et al. 2004). The estuary ranges 250 to 300m in the upper riverine region and 750 to 1000m in the lower region fronting the Indian Ocean. Sand dunes are found in both the southern and northern zones of the estuary. The estuary, including the congruent Malindi Bay, has experienced heavy sedimentation in the recent past. The deposition of dark brown clay forms mudflats in the lower middle region of the estuary. Along the beaches are found deposits of titaniferous minerals including mica, and quartz sand. The estuary is generally shallow with depth during high tide ranging from 2-6m. During low tide, water depths are usually less than 2m in most places (Kitheka et al. 2004).

The Estuary exchanges water with Malindi Bay. Water circulation is driven mainly by tides, discharge of freshwater from Sabaki Estuary and monsoon winds, which change direction seasonally. The seasonal change of direction of monsoon wind leads to changes in the movement of water in the bay Kitheka, et al., 2004).

There are no major dams in the Athi-Sabaki river (Snoussi et al. 2004). Most of the dams constructed within the Athi Basin are small sized and are located in the tributaries, particularly those draining the semi-arid zones of Eastern Kenya. They are principally used for domestic, livestock purposes. Within the main river, there are a few sand dams (low lying barriers erected across the river to trap coarse sediments in which water is abstracted in dry seasons by scooping sand from the channel bed.) Sand dams are major sources of water for people in semi-arid lands within the basin, particularly in Kitui, Makueni and Machakos districts (Kitheka et al. 2004). The situation may change in the future as Tana and Athi Rivers Development Authority (TARDA) have proposals for construction of large multipurpose dams across the Upper Athi Basin at Yatta, Munyu and Ndarugu.

A number of sources have noted the increase in sediment load (Fleitmann et al. 2007, Kitheka et al. 2004a&d). The sediment load of the Athi-Sabaki River has increased from 50, 000 tons.yr^{-1} in 1950s to 5.7 x 10^6 tons.yr^{-1} in the 2000-2003 period. The projected sediment load is 16 x 10^6 tons.yr^{-1} by the year 2050. The increase in sediment load could be attributed to changes in the flow of the Athi River as well as to land use changes. Land-use change in Athi-Sabaki catchment causing greatly increased sediment flux and discharge to sea.

Pangani River Basin

The Pangani river basin in Tanzania has a total area of 43,650 km^2 (PBWO/IUCN 2007). The river is found in north-eastern Tanzania and drains into the Indian Ocean. The main rivers in this basin are the Pangani River (which accounts for 27,300 km^2 and the coastal Rivers of Umba, Sigi and Msangazi, located in the south of the basin. The headwaters of Pangani River are in the Kilimanjaro and Mt. Meru (PIBO/IUCN, 2007). The major tributaries of Pangani River are Ruvu, Weruweru, Kikuletwa, Rau and Kikafu rivers.

Table 2.4: Key Features of Pangani River Basin

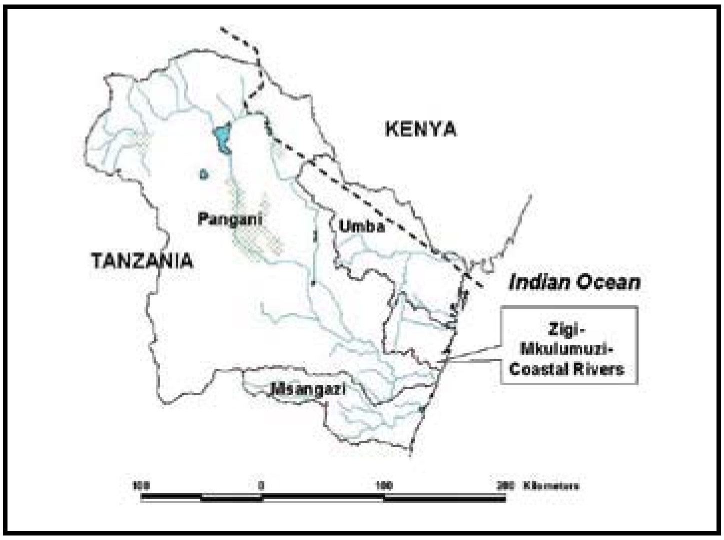
Basin Area	43, 650 Km2
River length	500 Km
Mean annual runoff	84 Km3
Population	2.6 million
Basin States	Kenya, Tanzania
Main water uses	Irrigation, hydropower generation

Source: Earle & Malzbender 2008

The name Pangani is assumed after the confluence of Kikuletwa and Ruvu at Nyumba ya Mungu (NYM) dam. The river then flows in the dry plains through extensive Kirua swamps and is joined by Mkomazi at Korogwe and then Luengera before passing the Pangani Falls into the Indian Ocean (Akitanda, 2007). From west Usambara the Umba drains north east and crosses the Tanzania-Kenya boarder before it enters the Indian Ocean. The Sigi river originates from the rather west east Usambara and flows eastward to the Ocean. The Msangazi (which is an annual river) originates from the drier Handeni plateau south of Pangani.

More than half of the Pangani basin is a semi-arid with average annual precipitation of 1,079mm per year (NLUC, 2006). The average rainfalls are recorded in the elevated areas of Kilimanjaro, Meru and Usambara Mountains range between 1,000 mm/year to 1,300mm/year. The main rainfall season is between March and May while short rains occur in the months of October to December. Inter-annual rainfall variability especially in the semi arid areas is common as reflected by frequent drought occurrences especially in parts of Arusha and Manyara Regions.

Figure 2.3: Map of Pangani River Basin



Source: Pangani Basin Water Office 2007

The macro-climate of the basin is controlled by the seasonal movement of the low pressure area known as the Inter-Tropical Convergence Zone. Convergence of the Northeast Trade Winds and Southeast Trade Winds, forces uplift of moist air resulting in a band of heavy rainfall around the equator. Variations in the local climatic conditions of the Pangani River Basin are related to topography. The flatter, lower-lying south-western half of the Basin is arid and hot, while the mountain ranges along the northern and south-eastern watershed boundaries are associated with cooler, wetter conditions.

The monthly river flow varies from 30 to 50 million cubic meters. The monthly volume is related to annual rainfall variability in the basin with the maximum values occurring in the wet season and the lower values in the dry season. Runoff values in the basin do vary from 1.2 mm/month to 11.9mm/month and is a related to precipitation with the higher amounts in the rainy season and lower amount in the dry season. The Pangani River carries little sediment. But in Pare and Usambara areas severe soil erosion has caused landslides, hence rivers from these areas carry a lot of sediments. (National Land use Framework Plan 2006).

A study on the hydrology of the Pangani River Basin (Beuster et al. 2006) used five key sites to illustrate extent of water resources development in the basin. The sites corresponded to the downstream outlets of the major catchments, i.e. the Kikuletwa and Ruvu catchments upstream of Nyumba ya Mungu Dam, the Mkomazi and Luengera catchments, and the outlet of the entire Pangani River catchment at the Pangani Estuary. Mkomazi catchment was found to be the most developed with about 58% of the catchment's natural runoff utilised, followed by the Kikuletwa catchment where about 25% of the natural runoff is currently utilised. In the upstream of the basin data shows that, in spite of large reductions in dry season flows, the river is still perennial because of contributions of the springs to surface flows in the middle part of the catchment. High water utilisation in the Mkomazi has resulted in a situation where the formerly perennial river is now mostly dry. A unique feature of the catchment relates to the occurrence of large flood events in the short rainy season of November to December, which are reduced in magnitude by Kalimawe Dam located in the middle part of the catchment. The same study reported that day inflows to the Pangani Estuary show a marked reduction in dry season high flows and wet season low flows, mostly due to flood interception at Nyumba ya Mungu and Kalimawe Dams while dry season low flows show relatively small reductions, in part due to contributions from the Luengera catchment and hydropower releases from Nyumba ya Mungu Dam.

The quality of the water in the river generally deteriorates from upstream to downstream (Lugeiyamu 2002) and most of the lower reaches of the river are classified by the State of the Basin Report as being "largely modified[4]" for parameters such as water quality, stream morphology and aquatic life. Poor quality is mostly related to increased levels of dissolved salts, nutrients, faecal coliforms, decaying organic material and turbidity in various parts of the system (PBWO/IUCN 2007). Dissolved oxygen levels in the estuary are very low, especially in the upper reaches before the diluting effect of seawater plays a role.

Rufiji River Basin

The Rufiji basin is the largest basin in Tanzania, covering on area of 177, 000 km^2, about 25 percent of Tanzania. The basin is comprised of three distinct river systems, namely: Great Ruaha River system, Kilombero River system and Lewegu river system. The Great Ruaha river system covers 83,920 km^2 of the Rufiji basin (or about 47% of the total). Important features of this sub-catchment are the Poroto mountain ranges, the Usangu and Panga plains and Utengule swamps.

Temperatures cause significant changes in the catchment, which is similar to water abstraction. Reduction in precipitation can have serious negative hydrological balance in the catchment. Other drivers with similar effects include population growth and degradation of watersheds caused by land use changes and siltation. The socio-economic aspects related to water abstraction and impoundment of the river, including the history and forecasting of land-use and demographic changes, and the changing demand for freshwater need to be studied. The coastal areas, especially in the delta, are adversely affected by sea-level rise associated with climate change.

[4] Ecological state: Severe modification with major disruptions in ecosystem functioning; mostly tolerant species remaining, often to pest proportions; alien species common; plants and animals may be diseased (PBWO/IUCN 2007).

The Great Ruaha system can be divided into three distinct river systems; namely, the Great Ruaha, the Little Ruaha and the Kisigo which originates from Manyoni and Rungwe Game Reserve. It drains the dry areas in the Ruaha National Park to join the Great Ruaha at Mtera reservoir. The Great Ruaha originates from the Paroto Mountains and Njombe highlands, where numerous rivers flow into the Usangu plains and the vast Utengule swamps. It then traverses through the Great Ruaha National Park and later joins the Little Ruaha before joining the Kisigo at Mtera. After Mtera, it joins with the Kilombero River system in the Kilombero plains before joining the Rufiji. The mean flow of the Great Ruaha at Mtera, at gauging site, station No. IKAS is 140 $m^3 s^{-1}$. The reservoir at Mtera is capable of holding the mean flow of the river. The river is completely regulated at Mtera the reservoir.

The Kilombero river system is 39, 990 km^2, about 23 per cent of the total area of the Rufiji basin. It, however, contributes 65% of the flow of the Rufiji River. Important features of the Kilombero basin are the great fertile Kilombero valley below the eastern scarp of the Udzungwa Mountains. Numerous rivers flow on the scarp from the Udzungwa plateau such as Ruhudji with mean flow of 140 $m^3 s^{-1}$ at Mwanya Mukungu, Mpanga (44 $m^3 s^{-1}$ at Mpanga), Ruaha, Kihansi, Luhombero, and Kigongo. The Ruhudji and the Luhombero form the Kilombero River (219 $m^3 s^{-1}$ at ifwema). After Shughuri rapid on the old basement step, the Kilombero joins the Luwegu flowing from southeast to form the Rufiji.

The Luwegu river system flows from the southeast and has a drainage area equivalent to 15% of the entire Rufiji basin. It consists of three major rivers namely, Luwegu, Mbarang'andu and Njinjo. The major part of this catchment is in the Sealous Game Reserve, which is conservation area and therefore unpopulated. This sub-basin is not at all gauged.

A significant proportion of the river water flows between levees that are 1 – 2 m higher than the flood plain. The suspended sediment concentration in the river is usually in the range 100 – 1000 mg/l, typical values for the dry and wet season being 150 and 500 mg/l respectively. The full discharge varies along the river, but it is usually in the range 2000 – 3000 m^3/s. The river discharge is rarely less than 100 m^3/s. Floods that exceed 12,000 m^3/s are uncommon with normal floods ranging between 600 – 800 m^3/s. The annual fresh water discharge is about 900 m^3/s. Annual sediment discharge is estimated at 15 – 25 million tons. There are two deposition sites: A minor deposition site at Mloka (on the Upper reaches) and a major deposition site on the delta and the coastline. It is reported that about 50% of the suspended sediment load of Rufiji River is advected through the river mouths and deposited in the nearshore are by wave action (Ochieng 2002). As a result of deposition of the sediment load carried by the Rufiji towards the coast, the shoreline has shifted seawards, protruding some 15 km into the Mafia channel (Euroconsult 1980c cf. Mwalyosi 2004).

However at present it appears that the delta is neither prograding nor eroding substantially, with the exception of local changes resulting from a re-distribution rather than a variation of sediment fluxes (Ochieng 2002).

Rovuma/Ruvuma River Basin

The Rovuma river basin is situated between about 10º S – 15º S of latitude and 32º E – 41º E of longitude and covers a surface area of 155, 400 km^2. Mozambique accounts for 65.5% (101,160 km^2) of the total area, Tanzania 34% (53, 330 km^2) and Malawi less than 1% (470 km^2). The river flows eastward for about 800 m (650 m in Mozambique) from its source close to Niassa Lake to empty into the Indian Ocean and is one of the main river basins in Mozambique.

Table 2.5 Key Features of Rovuma River Basin

Basin Area	152,000 Km2
River length	800 Km
Mean annual runoff	15 Km3
Basin States	Malawi, Mozambique, Tanzania
Main water uses	Subsistence agriculture, navigation and fishing

Source: Earle & Malzbender 2008

The mean temperature in the coastal area is 26°C and that of the hinterland is 24°C. Except for these raised plateaux, the land rises gradually from the Indian Ocean to the hinterland. There is only one dry season. The annual mean precipitation for the basin is 800 mm to 1,200mm. Floods normally occur in the flood pain of Ruvuma river where crops may be destroyed and occasionally occur on Matandu, Mbwemkuru and Mavuji river systems. Sediment transport in the basin varies from 2.5m^3/km^2/year in Lukuledi river system to 185m^3/km^2/year in Lumesule, a tributary of the Ruvuma river system (National Land use Framework Plan 2006).

The prevailing winds shape the climate of the basin. During the period November/December to April/May the dominant winds are from the north-east. They bring a hot humid rainy season to the region. When they blow from south-east the region becomes dry, cooler and less humid. The rainy season of November/December to April/May is single peaked, the peak being reached in January but occasionally in February or March. The amount of total annual precipitation tends to vary with altitude. In the coast rains vary from 935 mm to 116 mm in the hills and the plateau. In western highlands of the basin rainfall goes as high as 1,133 mm. Likewise temperatures vary from 27°C as the highest monthly mean on the coast in December to 23°C in July. Relative humidity goes from 87% in March to 79% in October in the coast. Temperatures and humidity are lower inland.

The topography of the region is divided into two. The coastal plain with its complexity of landforms, and the basement plain dominated by the Makonde Plateau with isolated rocky hills and steep river sides. The western half lying beyond the Makonde Plateau drains to the south through the tributaries of the Ruvuma River. The river has a tributary network formed by 8 main tributaries, from which three (Lucheringo, Lugenda and Muhuwesi) originate in Mozambique. The Rovuma river basin encompasses also the most pristine game reserve, the Niassa Game Reserve, and a variety of rich ecosystems consisting of wetlands, particularly the riverine systems. The Rovuma, its tributaries and associated ecosystems sustain the livelihoods of the riparian communities and represent a potential for tourist activities.

Observations from 1959 to 1966 indicate that the river has a mean annual runoff of about 11,220 million m^3. The maximum measured flow is about 3,100m^3/s, the minimum of 6.4m^3/s while the mean daily flow is 356 m^3/s. The river does not have a clear dry period. Data collected between 1952 and 1982 shows that from the estimated mean annual runoff about 10,000 million m^3 flows from the neighbouring countries while 18,000 million m^3 is generated in the country (DNA 1994). With a mean annual precipitation of about 1,100mm the basin has a surplus annual runoff of about 2,800 million m^3 (Pitma et al. 1994).

Zambezi River Basin

The Zambezi River basin is the fourth largest in Africa after the Congo, Nile and the Niger. Rising from the Kalene Hills in the North Western Province of Zambia flowing south and then eastwards for some 2,650 km to the Indian Ocean the Zambezi River crosses through eight riparian states - Angola, Botswana, Malawi, Namibia, Tanzania, Zambia and Zimbabwe. The main stem of the river forms the southern border of Zambia with Namibia, Botswana and Zimbabwe, before flowing consecutively to Mozambique – where it terminates in the Indian Ocean (Earle & Malzbender 2008). Table 2.4 presents the basin characteristics in the basin countries.

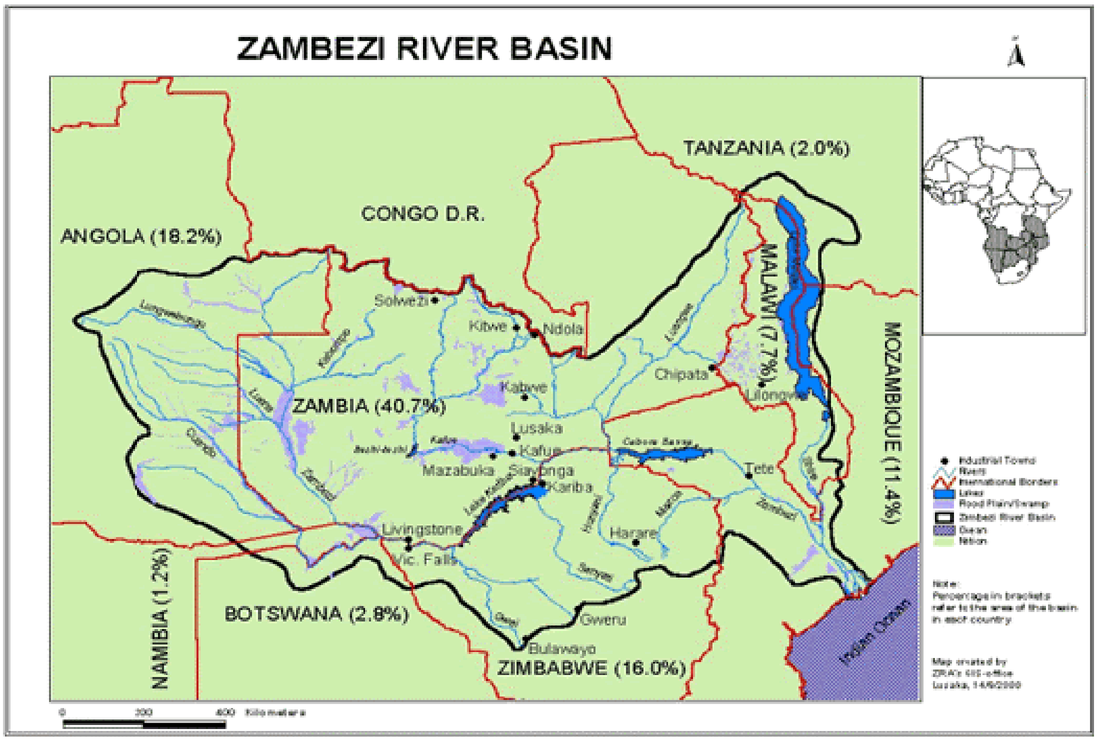


Figure 2.4: Zambezi River Basin Map

Source: Zambezi River Authority

Table 2.6: Key Features of Zambezi River Basin

Basin Area	14, 000,000 Km2
River length	2650 Km
Mean annual runoff	106 Km3
Population	45 million
Basin States	Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe
Main water uses	Hydropower generation, commercial fishing, irrigation, industrial and domestic uses

Source: Earle & Malzbender 2008

The following apply relating to the different sections on its journey to the Indian Ocean:

- The River rises in the Kalene hills in north-western Zambia and flows northwards for about 30 km, turns west and south for about 280 km through Angola and re-enters Zambia with an annual discharge of nearly 18 km^3 and continues southwards through marshy plains (AUF nd.a)
- In south-west of Zambia the river forms the border between Zambia and the eastern Caprivi Strip of Namibia for about 130 km (AUF n.d.a)

- The Chobe tributary, which originates in Angola, crosses the Caprivi Strip with an annual discharge of about 1.3km^3, forms the border between Namibia and Botswana and enters Botswana to flow southwards for about 75 km until it meets the Selinda spillway along which spillage from the Okavango occurs in high flood years. It turns east, forming the border between Namibia and Botswana as it flows through a swampy area and flows into the Zambezi River at the border point between Namibia, Botswana, Zimbabwe and Zambia with an annual discharge of about 4.1 km^3. The discharge of the Zambezi River at this point is 33.5 km^3/year (FAO, 1997)
- The River forms the border between Zambia and Zimbabwe and reaches its greatest width, over 1.3 km, before it plunges over the Victoria Falls and continues to form the border between Zambia and Zimbabwe until it enters Mozambique (FAO, 1997)
- Downstream of Lake Kariba the tributary Kafue River which originates in the north of Zambia, flows into the Zambezi River with a discharge of about 10 km^3/year (FAO 1997)
- At the border with Mozambique, the tributary Luangwa River flows into the Zambezi River with an annual discharge of over 22 km^3, which originates in the north-east of Zambia. The total discharge entering Lake Cabora Bassa from Zambia is estimated at about 77.5 km^3 /year (AUF n.d.a)
- Beyond Lake Cabora Bassa the River flows south-eastwards and receives water from its last great tributary, the Shire, with an annual discharge of nearly 16 km^3. The Shire drains Lake Malawi (also called Lake Nyasa) about 450 km to the north. The northern part of Lake Malawi forms the border between Tanzania and Malawi, the southern part the border between Mozambique anti Malawi. The total flow into the lake is estimated at about 29 km^3/year of which, 53% is from Tanzania, 43% Malawi and 4% Mozambique. Total outflow from the lake in the Shire River in the south is 12.5 km^3/year. The level of the lake has fluctuated 6 metres since the beginning of the century, with its lowest level in 1917 and its highest level in 1980 (FAO 1997)
- At its mouth, the Zambezi River splits into a wide, flat and marshy delta with annual discharge flowing to the sea estimated at 106 km3 (FAO 1997).

There are two major man-made lakes on the Zambezi River, Lake Kariba on the border between Zambia and Zimbabwe and Lake Cabora Bassa in Mozambique (AUF n.d.a). These two dams were built for hydroelectric power generation and have a capacity of 1, 266 MW and 2, 075MW, respectively, the largest in the southern African region (Chenje and Johnson 1996).

About 40 hydroelectric plant sites have been identified in the Zambezi –85% of this capacity is on the Zambezi River and the remainder on the tributaries with about half of the potential in Mozambique, 25% in Zambia and 20% in Zimbabwe (Matiza et al. 2002). The fact that hydroelectric power is one of the cheapest sources of energy is likely to spur the development of the identified sites more so because the Southern African region is now short of power. This means that runoff will be modified as happened with the construction of the Kariba and Cabora Bassa dams.

Water transfers can also modify the flow of the river. Proposals to transfer water from the Zambezi River to provide water to parts of Zimbabwe, Botswana and even South Africa will further alter the runoff characteristics of the river. This is also true if dams are constructed for irrigation. .

Data on sediment loads in the basin is scarce especially that relates to the quantity and quality of sediment deposits at the delta, which covers an area of about 18 000 km^2 from its apex at Chupanga to its 120 km front with the Indian Ocean coast from Quelimane southwest to Machesse. The most important influence on the hydrology of the delta is the seasonal floodwaters of the Zambezi River and its distributor channels, and perennial runoff from streams draining the Cheringoma plateau from the west.

Pungwe River Basin

The Pungwe originates in the Zimbabwe Highveld (Inyangani mountain system) at an altitude of more than a 1000 m above sea level. It travels 395 km eastwards into the Indian Ocean (Van der Zaag 2000). In the north and eastern part of the basin the climate can be described as tropical rain savannah climate dominates the northern and southern part of the basin while the rest is characterised by humid temperate climate. Mean annual rainfall over the catchment area varies with altitude. While the average figure for the catchment is approximately 1,114 mm, highest figures of about 1,500 mm and 1,700 mm/yr are found in the highlands region of Catandica, Pungwe Frontier, and Serra da Gorongosa. Lowest figures corresponding to driest areas occur in the northern part of the basin, including Guro, Macossa, Piro and Zongorgue, and the region southwards the Urema, Chitengo, Pungwe, Lamego, and Nhamatanda up to Mandine and Guara-Guara region, where rainfall vary within the range of 600 and 800 mm/yr. The summer rainy season generally lasts from October to March; the wettest month depending on the region can be either January or February with the dry season lasting from May to September. The driest months are June and October.

Table 2.7: Key Features of Pungwe River Basin

Basin Area	32,500 Km2
River length	300 Km
Mean annual runoff	3 Km3
Basin States	Mozambique, Zimbabwe
Main water uses	Irrigation, Fishing

Source: Earle & Malzbender 2008

The hottest months are January and February and are characterised by temperatures ranging from 17ºC and 28ºC while the coldest months are June and July, and experience temperatures ranging from 11ºC and 21ºC. The mean annual potential evapotranspiration varies from about 1300 mm in some of the mountainous regions of the catchment to about 1600 mm in the coastal areas and lowlands.

The average annual flow in the order of 5,500 Mm^3. The main rivers of the catchments area on the left bank are the Messambedze, Nhyazonia, Txatora, Vanduzi, and Urema-Mucumbedze-Nhondugue and, on the right bank, the Honde, Mavuzi, Mucumbedze, Marionda, Mezingadze, Messatua, Metuchira and Muda rivers.

The river can be divided into three sections. The upper section refers to the portion where the river rises from the foothills of Mount Inyangani in eastern Zimbabwe. The middle portion is that section that flows into Honde Valley where it crosses into Mozambique. Up to the point at Bué Maria where it reaches the plains it is referred to as the lower part of the basin. Downstream of Bué Maria the river divides in several streams, which join again near the bridge over the Pungwe River which is situated some 100 km from the estuary mouth. At the estuary the Pungwe waters enter the Indian Ocean. This is some 20 kilometers north-west of the City of Beira.

The discharge at Bué Maria is said to have critical environmental implications. It pushes back the salt sea water intruding through the estuary, which is crucial for the City of Beira's water supply intake. The 10% low flow (i.e. the flow with a chance of occurring of 0.10; with a return period of 10 years) at Bué Maria has been established at 8.8 m^3/s (Zanting et al. 1994). A flow of 10m^3/s is considered the minimum flow to safeguard the intake of fresh water for Beira (Van der Zaag 2000).

No dam has been developed on the river. However, in 1999 a pipeline that transfers water from the Pungwe River to the Odzani catchment (a part of the Save River basin) to augment Mutare Town (in Zimbabwe) was constructed. The quantities involved are 0.7m^3/s or 22 million m^3 per year. The agreement with Mozambique is that Mutare can abstract 0.7 m^3 provided there is always $0.5m^3/s$ in the river. Van der Zaag (2000) contends that the diverting of $0.7m^3$ is significant as this is equivalent to 16% of the mean annual runoff. During the low flow season this is much larger equivalent to 50% of the mean annual runoff during September the month of the lowest flow although this is considered small as at the border with Mozambique the discharge is larger due to a bigger catchment.

Limpopo River Basin

The Limpopo River Basin is located in the east of Southern Africa between approximately latitudes 20°S to 26°S and longitudes 25°E to 35°E. It has a mean altitude of 840 m above sea level and covers an area of about 413, 000 km^2 (FAO-SAFR 2004). Table 2.6 shows the respective proportions of the basins in the riparian countries.

Table 2.8 Proportion of Limpopo basin in the riparian countries

Country	Proportion of country area (%)	Proportion of basin area (%)
Botswana	11.7	24.8
South Africa	8.4	36.5
Mozambique	7.4	20.9
Zimbabwe	12.8	17.8
Total	9.4	100

Source: AUF (nd.b.)

Average annual temperatures are practically the same throughout the basin (24º C). The exception is the north eastern side where it goes as low as 22º C. On the coastal and north-eastern areas, the average maximum daily temperatures are 30º and 32º C and in the central area 34º C. Average temperature in the hottest month is 28º C and the lowest 26º C, the annual variation of these temperatures is between 6º C and 9º C. The annual average relative humidity in the central area is 65%, increasing to the north and south to reach the highest rate of 75%. Average annual evaporation is 1, 970 mm and ranges from 800 to 2400 mm $year^{-1}$ (Challenge Programme, 2007) and exceeds average annual rainfall.

Rainfall varies dramatically across the basin, from 860 mm $year^{-1}$ near the coast to less than 300 mm $year^{-1}$ in the arid central regions. The rainfall seasonality both during the summer months (October to March) and winter months (April to September), is explained by the presence of anti-cyclonic conditions over the whole southern Africa. Approximately 95% of the annual precipitation in Mozambique occurs between October and March, in a number of isolate rain days and isolated locations, characterizing the cyclic seasonal, erratic and unreliable precipitation (cyclic droughts and floods events. The total annual runoff generated in Mozambique is in the order of 400 milion m^3 $year^{-1}$.

Runoff is estimated to be 5.5 x 109 m^3 per annum (Challenge Programme 2004). Just like the Zambezi River runoff in the basin is intimately related to the different sections of the river on its journey to the Indian Ocean. (AUF n.d.b) provides a summary of the runoff in the basin thus:

- The Krokodil headwaters at Hartbeespoort Dam are characterised by a discharge of 152,954, 000 m^3 with maximum flow in February and minimum in August
- Water produced in Botswana is estimated at 0.6 km^3/yr
- Surface water produced in the basin in Zimbabwe is estimated at 0.54 km^3/year of which 0.41 km^3/yr drains into the Limpopo at the border between Zimbabwe and South Africa
- The Mozambican part of the basin is estimated to contribute 10% of the total mean annual runoff. The river is no longer perennial and can be dry up to 8 months per year.

The river and its larger tributaries exhibit marked seasonal cyclical patterns of high and low flows and many of the smaller tributaries are entirely seasonal or episodic (Ashton *et al.* 2001). In Mozambique three important tributaries join the River. The Nuanedzi River on the right hand side of Limpopo (rising entirely in Zimbabwe) and joins Limpopo after running for about 60 km in Mozambique; the Changane River (rising close to Zimbabwe border) joins the Limpopo close to its mouth on the coast near to Xai-Xai town (SARDC 2003); the Elephants River joins the Limpopo River after the Massingir reservoir (Louw and Gichuki 2003). Other important water resources in the Limpopo River Basin in Mozambique are the wetlands, which generally are found distributed throughout the swamps areas along the rivers, e.g. swamps after the confluence of Limpopo River with the Elephant River, riverine floodplains as the Limpopo River approaches the confluence with the Changane River (Brito *et al.* 2003).

The major structures influencing the flow in the River in Mozambique are the Massingir and Macarretane dam, with the main purpose of lifting the water (± 5 m) to allow diversion of water to Chókwè irrigation scheme is totally dependent on the flows discharged by Massingir dam. The Macarretane dam is placed at the Limpopo River (main course) close to Chókwè town (16 km upstream) and has a small reservoir with a maximum capacity of 4 Mm^3 (SAFEGE 1995). On the other hand, the Massingir dam is placed at the Elephants River (tributary of Limpopo) and has a reservoir with a maximum capacity of 2800 Mm^3 (DNA/ARA-Sul 2006).

There are more than 43 dams with a storage capacity of more than 12 million m^3 which supply water to urban areas and are also utilized for industry and agriculture (Chenje and Johnson 1996). The river has been developed to its full potential in South Africa and almost full potential in South Africa, which impacts on downstream river flow.

For dams see section 2.10.2. According to the Challenge Programme (2007) Water is transferred into the basin under six separate water transfer schemes. The heavy flooding that occurs from time to time in the floodplains in Mozambique suggests that sedimentation can be a problem. Unfortunately there is no available data to show the state of affairs.

Incomati River Basin

The Incomati basin has a total basin area of about 46,800 km^2 (which makes it is one of the largest in Southern Africa) comprising 63% in South Africa, 5% in Swaziland and 32% in Mozambique (Carmo Vaz and Perreira 2002). This corresponds to 28,600 million m^3, 2,500 million m^{3} ^{d} and 15,600 million m^3 ^{2}fall respectively. The general climate varies from a warm to hot humid climate over the Mozambique coastal plane and Lowveld regions to a cooler dry climate over the Transvaal plateau and Highveld areas in the west. Mean annual temperature in the Incomati basin varies from 22.5ºc in the east to about 15ºc in the South Africa Highveld in the South west of the basin. The basin falls within the summer rainfall region with the rainy season usually lasting from October to March. The average mean annual precipitation is about 736mm and varies from an average of 600mm in the Mozambique coastal plain to about 1400mm in the Middleveld region. Mean average annual gross pan evaporation for the basin is 1,900mm and generally increases from about 1700mm in the high lying south to about 2100mm in the low lying north.

The river rises up to some 2000 m above sea level in South Africa, in an area that is rich in coal deposits, part of the river then flows into Swaziland, it subsequently flows back into South Africa, where it is heavily used for agricultural purposes before finally flowing into Mozambique where it discharges into the Indian Ocean just north of Maputo (shown on figure 2.5).

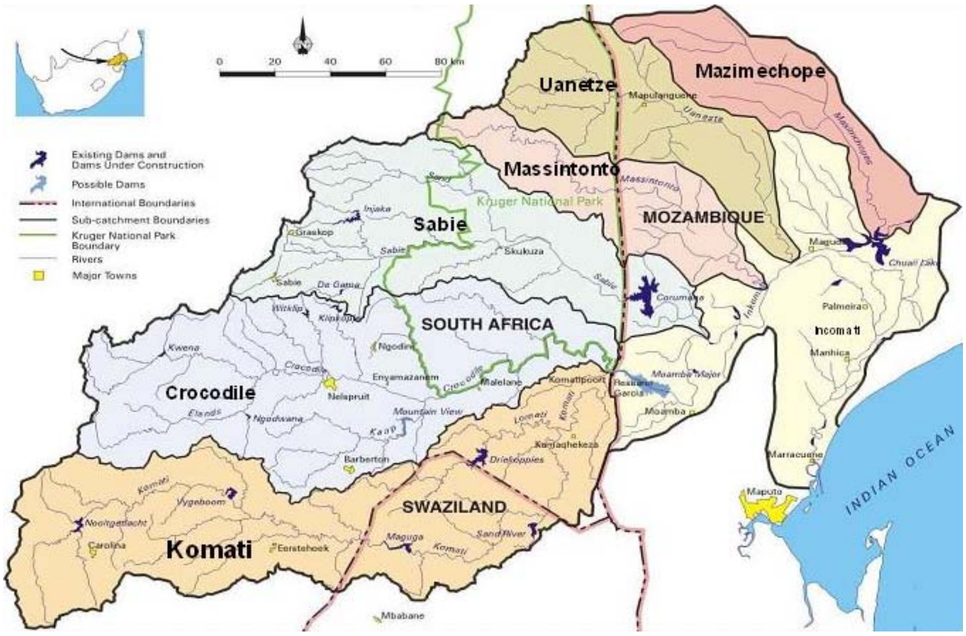
Table 2.9: Key Features of Incomati River Basin

Basin Area	46 700 Km^2
River length	800 Km
Mean annual runoff	3.5 Km^3
Population	2 million
Basin States	Mozambique, South Africa, Swaziland
Main water uses	Irrigation, Forestry and Industry

Source: Earle & Malzbender 2008

The river drains into Maputo Bay, in Mozambique. The annual average rainfall and of evapo-transpiration are 740 mm and 1900 mm, respectively. The average discharge is about 200-400 m^3 s^{-1}, corresponding to about 700-1,000 million m^3 per year. The regime of the Incomati River is characterised as torrential with high flows during the wet season, from November to March and relatively low flows in the dry season, from April to October. In average 60% to 80% of the mean annual flow occur in few months of the year (DNA, 2000).

Figure 2.5: Incomati River Basin Map



Source: Dlamini 2005

The net contributions to the total net natural mean annual runoff (mean annual runoff in the natural condition without any land and water use effects and allowing for river channel losses) (MAR) of the Incomati watercourse at the estuary by the various catchments is about of 3 590 million m^3 (South Africa contributes 82%, Swaziland 13% and Mozambique by about 4%. Average annual evapotranspiration estimated at about 1900 mm exceeds the precipitation estimated at about 740 mm.

There are large numbers of dams in the basin, 22 of which can be classified as large. Most of the dams are located in South Africa. Mozambique has only one large dam, the Corumana Dam that was completed in 1988 and serves mainly as the storage component of an irrigation system (Carmo Vaz and Perreira 2002). These have significantly modified runoff patterns in the lower part of the basin in Mozambique.

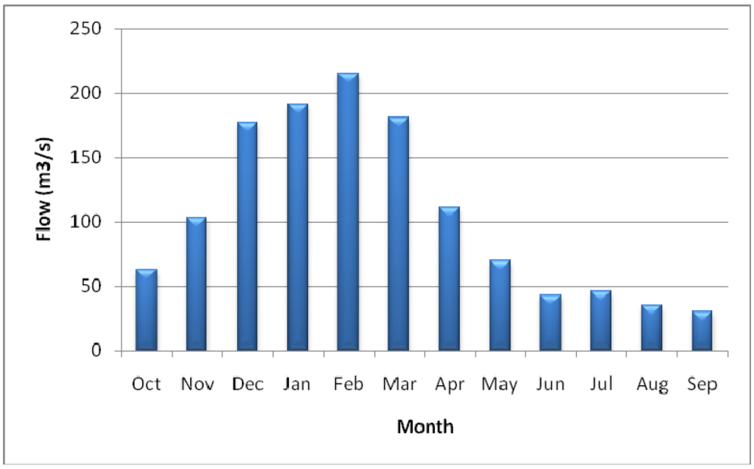
Maputo River Basin

The Maputo River Basin is situated between the parallels 26º00'and meridians 30º45' and covers an area of about 29,800 km^2. It is shared by three countries: South Africa and Swaziland both with 93.9% (28, 230 km^2) and Mozambique with only with 6.1% (1570 km^2). The river has two principal tributaries, namely the Usutu and the Pongola. Most of the area by the Usutu lies in Swazi and that drained by the latter in South Africa. Within Mozambique the River passes through the Libombos range and there flows a northerly course until it discharges into Maputo bay.

The mean annual rainfall ranges from 1,054 mm near the coast to 388 mm inland. There is a defined season of 5 to 7 months during the summer. The mean annual temperature varies from 22.1 ºC to 23.0 ºC. The mean maximum being 26 ºC while the maximum recorded temperature is 47.1 ºC and the minimum is 1º C. The variation of temperature increases in a gradient from the coast towards inland. Relative air humidity varies between 67.3% and 80.5% decreasing away from the coast, with increasing altitude. Winds are usually from the south east with the mean velocities of 3.4 to 9.5 km/h, and strongest winds occur between August and October. Evaporation increases from August to a maximum between January and March. The annual potential evapotranspiration is about 1500 mm, with the maximum annual deficit being 876 mm.

The mean annual runoff generated in the Basin is about 2,900 million m^3, of which 100 million m^3 is generated in Mozambique. Estimates of the mean monthly flows for an average year are shown in Figure 2. 3. From this figure is clear that on average the minimum flow occurs in September, but low flows can also occur at any time between April and November. In dry season the mean monthly flow, with probability of 80% is only 12 m^3/s.

Figure 2.6 Mean monthly flow for an average year for Maputo River



Source: DNA 1982

There are no dams on the Maputo River within Mozambique. There are however seven small earth dams, all less than 6 m of height. These dams have a total storage capacity of about 133,000 m^3, all used for the watering of the livestock.

Thukela River

The Thukela River rises in the Drakensberg Mountains very close to the border with Lesotho and meanders through central Kwazulu Natal and discharges into the Indian Ocean. The tributaries include the little Thukela, Klip, Blonkrans, Sundays, Mooi and Buffalo. Rainfall in the catchment ranges from 1,500mm per annum in the mountains to 650 mm per annum in the central parts of the catchment. Runoff is substantial and is estimated at 3,799 million m^3 / annum.

Betsiboka River Basin

The Betsiboka River Basin is one of the biggest catchment areas of the Malagasy hydrographic system in terms of annual discharge and total basin area. It is usually combined with the Mahajamba River basin northward making the catchment area up to 63,500 Km^2 (Chaperon et al, 1993). The river basin traverses the humid central highland with an average annual rainfall between 1,500 to 2,000 mm and the less humid western sedimentary zone having an average annual rainfall ranging from 1,300 to 1,500 mm (Chaperon et al, 1993). The River originates in the central highlands part of Madagascar near the "Falaise de l'Angavo" at 1,755 m above sea level (Shahin 2003) and flows north-westward and discharges into Bombetoka Bay forming a large delta near the city of Mahajanga. Major tributaries are Ikopa and Isandrano in the central highlands part and

Menavava, and Mahajamba in the western sedimentary zone. The river catchment areas drain the cities of Antananarivo (the capital), Maevatanana, and Marovoay. The Ikopa tributary basin has large dams at Mantasoa and Tsiazopaniry, and it is the main source of drinking water for estimated to be 1900,000 inhabitants of Antananarivo (INSTAT 1997).

The flow regime, of tropical type, is closely related to the precipitation pattern or rainfall-dependent regime. The monthly mean discharges recorded during the rainy season (December to March) range between 414 to 695 m^3/s, while they decrease significantly up to 167 to 295 m^3/s during low season. Flash floods are chiefly caused by extreme weather conditions occurring usually during cyclonic events. The River is distinct for its red-coloured water which is caused by the sediment emanating from highly eroded/degraded catchment areas, due to the practice of bush fire and slash and burn before the rainy season. The high concentration of free iron oxide in sediment gives the water its red-colour (Lebigre 1990). A floodplain is developed in the lower course containing some 150 small lakes (IWMI 2006). These include Amparihibe-south (12.5 km^2), Ambania (9.1 km^2), Amboromalandy (6.6 km^2) and Bondrony and Matsiabe (5.0 km^2 combined). Total area of the lake is 80 km^2. The floodplain in the lower course, in the Marovoay region, is among the rice growing zones of Madagascar.

Tsiribihina River

Tsiribihina River drains a basin as big as Betsiboka basin of 46300 km^2, of which 73% is located on the crystalline shelf (highlands part) and 27% in the sedimentary basin (Lebigre 1990). From the central highland humid zone to the lower semi-arid sedimentary zone the average slope of the course ranges between 0.02% to 0.32% (Lebigre 1990). The river is the third largest river in Madagascar in terms of annual mean discharge (Lebigre 1990). There are two main tributaries namely Mahajilo and Mania Rivers, which join to form the Tsiribihina River. The average annual precipitation within the River Tsiribihina basin ranges between 1,200 to 1,900 mm in the highlands part and 900 to 1,200 mm in the sedimentary part (Lebigre, 1990). The Tsiribihina basin is also strongly affected by bush fire practice and heavy agriculture land use within its catchment areas. The sediment load reaching the delta zone consists of sand, clay and silt poor in organic matter, but may get high concentrations in organic matter from mangroves degraded vegetal material (Lebigre 1990).

Mangoky River Basin

Situated in the south-western part of Madagascar the Mangoky River Basin is the biggest catchment of the Malagasy river system in terms of area (55,750 km^2). It originates in the southern part of the highlands nearby Peak Boby at 2,658 m above sea level in the mountain of Andringitra. The main tributaries are namely Mananantanana, Matsiatra and Zomandao, which join at the crystalline shelf and sedimentary contact zone located at about 300 km of the sea (Aldegheri 1967). The upstream basin of the Mangoky is situated on the crystalline shelf. The river traverses the south-western sedimentary zone in a quite a large bed (1 to 2 km wide) with very unstable banks. Downstream, the large floodplain (5 to 6 km wide) is usually used for the cultivation of beans and peas after the drop in the water level. Close to the mouth in the Bas-Mangoky region, known as a rice growing zone, constitutes a permanent inundated area during the flood period. The Mangoky basin is home to medium sized urban settlements such as Ambalavao, Beroroha, and Tanandava. The little referenced hydrological and sedimentary date which exists for the basin suggest that the basin is less affected by human activities such as bush fire practice than those of Betsiboka and Tsiribihina. This is probably due to the location of the course of the river mostly away from bigger settlements. The Mangoky River flow regime is highly affected by the semi-arid climatic condition in the South-western sedimentary zone. The monthly mean discharge is between 1,370 and 1,500 m^3/s in January and February.

Fiherenana River Basin

The major part of the Fiherenana River Basin is located in the south-western sedimentary zone of Madagascar, which is characterized by its climate semi-arid. The South western part of the country is the driest of Madagascar. The annual average precipitation falling on the former southern provincial capital, namely Toliara located in the WIO, was estimated to be 341 mm in 34 days (Lebigre 1990). The rainfall is irregular although mostly concentrated in December to March in a heavy local storm form. This is the principal cause of flooding affecting major part of the city of Toliara, the last one recorded occurred in February 2005. Further, flash floods often cause the displacement of the river bed while massive sediment loads are transported into the ocean damaging the great reef barrier in the Bay of Toliara. The Fiherenana River Basin is affected by bush fire and slash and burn practices. Destruction of forest for charcoal and maize culture is very important in order to supply the city of Toliara home to 175,937 inhabitants (INSTAT 2005).

2.5 Governance Framework

2.5.1 International and Regional Conventions

A number of international and regional conventions, and the work of related institutions, are relevant to meeting the increasing challenge posed by land-based sources and activities that cause pollution and degradation of the marine environment in the WIO region. The two main international conventions are United Nations Convention on the Law of the Sea and the Nairobi Convention.

The first concerted effort to regulate marine pollution generally and land-based marine pollution specifically at the international level emerged with the adoption of the 1982 UN Convention on the Law of the Sea (UNCLOS). Part XII (Articles. 192 to 237) of UNCLOS is devoted to "Protection and Preservation of the Marine Environment". Of particular relevance are articles which impose an obligation on states to protect and preserve the marine environment (Article 192); a duty imposed on states to take measures that are necessary to prevent, reduce, and control of the marine environment (Article 194) and specifically Article 207, headed "Pollution from Land-based Sources".

The central and key regional convention is the 1985 Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region, (the 'Nairobi Convention'). The Nairobi Convention provides a framework for regional cooperation in the protection, management and development of the WIO region's marine and coastal environment, for sustainable socio-economic growth and prosperity. A particular strength of the Nairobi Convention, with strong relevance to the WIO region, is that all ten countries referred to above are parties to it. The convention was adopted in 1985 together with its two original protocols. The first is the Protocol Concerning Protected Areas, Wild Fauna and Flora in the East African Region (the 'SPAW Protocol') which recognises the danger from increasing human activities threatening the environment of the Eastern African region; and that natural resources constitute a heritage of scientific, cultural, educational, recreational and economic value that needs to be effectively protected. The second is the Protocol concerning Co-operation in Combating Marine Pollution in Cases of Emergency (the 'Emergency Protocol'). A third (draft) Protocol on LBSA to the Nairobi Convention was presented by the Nairobi Convention secretariat to the fifth conference of parties (COP 5) in November 2007 in Johannesburg, South Africa. The development of this Protocol is a tacit acknowledgement of an existing legal gap to confront the increasing challenge and severity of land-based sources and activities causing pollution and degradation of the marine environment in the WIO region.

The UN Convention on the Law of the Non-Navigational Uses of International Watercourses 1997 is particularly relevant to the five terrestrial WIO countries given the aridity of the region and the likelihood that the problems associated with drought, are likely to be exacerbated by climate change. The Convention obliges watercourse states to protect, preserve, and manage international watercourses and their waters (see Article 1(1)) and specifically to protect and preserve watercourse ecosystems (Article 20). It defines 'watercourse' as "a system of surface waters and ground waters constituting by virtue of their physical relationship a unitary whole and normally flowing in a common terminus"; an 'international watercourse' is defined as "a watercourse, parts of which are situated in different states"(Articles 2a & b). Article 3 of the Convention encourages the adoption of watercourse agreements at a regional level and to this end a South African Development Community (SADC) Water Protocol, later a Revised Water Protocol, was adopted. The convention goes on to oblige states to prevent, reduce and control pollution, in particular in harmonising their policies. The measures advocated include setting joint water quality objectives and criteria, establishing techniques and practises to address pollution from point and non-point sources, and establishing lists of substances whose introduction is to be prohibited, limited, investigated or monitored (Article 21).

Other international conventions that are related to and directly relevant to land-based sources in the region include:

- Convention on the Non-Navigational Uses of International Watercourses based on the articles drafted by the International Law Commission, adopted by the UN General Assembly 1997 ("Watercourse")
- Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 ("London")
- Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972/ 1996)
- International Convention for the Prevention of Pollution from Ships (1973/78). ("MARPOL")
- Convention on Biological Diversity, 1992 ("CBD")
- Convention on Persistent Organic Pollutants, 2001 ("Stockholm")
- Convention on the Prior Informed Consent Procedure for certain Hazardous Chemicals and Pesticides in International Trade, 1998 ("Rotterdam").

The international conventions described above embrace a broad range of issues and responsibilities that would appear to ensure sustainable utilization of the marine and aquatic resources and environment of the WIO region. However, accent to the terms and responsibilities of and thus signatory to the conventions is not uniform throughout the region owing to the following key challenges:

(i) Inadequate Technical Capacities

(ii) Inadequate Financial Capacities

(iii) Overlapping/Uncoordinated Institutional Mandates

(iv) Multiplicity of Sectors affecting LBSA Issues

(v) Lack of or inadequate Political Goodwill

(vi) Language and Legal System Constraints

(vii) Multiplicity of Regional Affiliations

(viii) Political Instability.

2.5.2 Soft Laws and related developments

There are five important 'soft' laws that have been established over the last twenty years that are relevant to the WIO region: namely Agenda 21, Montreal guidelines, Washington Declaration and Global Programme of Action on Protection of the Marine Environment from Land-Based Activities (GPA), World Summit on Sustainable Development and Johannesburg Plan of Implementation and UNEP's Regional Seas Programme.

2.5.3 Regional Economic Integration Agreements

The WIO region stretches across four regional economic integration units which mainly focus on the economic integration and not necessarily environmental considerations. All four (SADC, COMESA, the EAC and the IOC) must be seen against the backdrop of the Nairobi Convention which is the regional springboard for implementing LBSA implementation mechanisms at national level. Four WIO countries are not members of SADC including Comoros and Kenya; similarly four are not members of COMESA including South Africa and Tanzania; by its nature only three coastal countries are members of the EAC; and only the island states are members of the IOC. However, each can play a role in one way or another of at least generating political momentum behind efforts to combat land-based marine pollution. Thus for example, if the SADC, (as described in the next paragraph), had an environmental assessment protocol, it would provide the momentum for the adoption of such laws in other countries in the region. Such a framework is discussed further in the conclusion of this section. A matter of consideration under the review of regional agreements is the possibility of linking both the Nairobi and Abidjan Conventions to SADC, the IOC, and/or other relevant regional integration units in some way such as by an inter-governmental agreement. This could be achieved by both the Nairobi and Abidjan conventions adopting a land-based marine pollution protocol and linking this to the LME programmes described below, thereby taking into account ecological considerations.

In as far as trans-boundary issues are concerned; resource management and environmental issues are accommodated particularly well in the SADC protocols, notably the Shared Waters Protocol. In light of this opportunity, a recommendation of this is that a concerted effort be made to promote the development of a SADC environmental assessment Protocol which would include land-based marine pollution considerations. Given that it is unlikely that such a Protocol will be developed for SADC in the near future, an interim measure would be to incorporate a land-based marine pollution clause in the draft Protocol on Land-based Sources of Marine Pollution which is currently being prepared.

2.5.4 International and Regional Institutions

There are six principal international institutions involved in economic development and the marine environment of the WIO region:

United Nations Environment Programme (UNEP): Although it is an international institution, its physical location in Nairobi makes it a central player at the regional African and WIO level. It among many other things initiated the international Regional Seas Programme (RSP) above including the central convention to this report, the 'Nairobi Convention' and its two protocols.

UN Development Programme (UNDP): The UNDP is involved by virtue of being the principle channel of multilateral, technical and investment assistance to developing countries, and includes various environmental programmes, such as the GEF (Global Environmental Facility) which not only makes funds available to developing countries but has also initiated capacity-building programmes

African Ministerial Conference on the Environment (AMCEN): The African Ministerial Conference on the Environment (AMCEN) was established in December 1985, following a conference of African ministers of environment held in Cairo, Egypt. AMCEN led the process for the development of the action plan for the Environment Initiative for the New Partnership for Africa's Development. It endorsed a framework a specific NEPAD Environment Action Plan which commenced in 2002 early on in the NEPAD initiative, which was also endorsed by the African Union in the same year.

The Environment Action Plan is underpinned by the notion of sustainable development in that in takes consideration of economic growth, income distribution, poverty eradication, social equity and better governance. It is organised in programme clusters and project activities to be implemented over a period of ten years. AMCEN has provided guidance in the process for the implementation of the action plan for the environment initiative of NEPAD, including its work programme for the biennium 2005-2006.

New Partnership for Africa's Development (NEPAD): NEPAD is a vision and programme of action for the development of the African continent, formulated by African leaders throughout the African Union and adopted in October 2001. It is a comprehensive integrated development plan that addresses key social, economic and political priorities for the sustainable growth of Africa. The goals of NEPAD are broad and include promoting accelerated growth and sustainable development, eradicating widespread and severe poverty, and halting the marginalization of Africa in the globalization process.

The African Process for the Development and Protection of the Coastal and Marine Environment in Sub-Saharan Africa (the 'African Process') and the Pan African Conference on Sustainable Integrated Coastal Management (PACSICOM): The underlying motivation for the African Process is the recognition of the need for regional cooperation to maximize capacity to address the many social, economic and environmental problems that are either transboundary in nature, or common to most countries. The initiative drew from scientific expertise, such as the Western Indian Ocean Marine Science Association (WIOMSA), within individual countries to identify priority areas for action. It has led to the incorporation of a coastal and marine sub-component of the environment component of the NEPAD Action Plan referred to above. The African Process has a secretariat known as the NEPAD Coastal and Marine Secretariat (COSMAR) and is based in Nairobi, Kenya.

African Ministerial Conference on Water (AMCOW): The Mission of AMCOW is to provide political leadership, policy direction and advocacy in the provision, use and management of water resources for sustainable social and economic development and maintenance of African ecosystems, and strengthen inter-governmental cooperation to address the water and sanitation issues in Africa. Its functions include: facilitating regional and international cooperation through the coordination of policies and actions amongst African countries regarding water resource issues; reviewing and mobilizing additional financing for the water sector in Africa; and providing a mechanism for monitoring the progress of implementation of major regional and global water resources and water supply and sanitation initiatives.

2.5.5 Intergovernmental Agreements

A number of Africa-wide, sub-Saharan and WIO region inter-governmental arrangements, agreements and frameworks exist which focus generally on shared natural resource management, more particularly around marine fisheries, marine ecosystem management, and freshwater management.

- Marine fisheries management
- Large Marine Ecosystems (LME) Programmes
- Transmap

2.5.6 River-basin governance frameworks

The management of international watercourses through regional cooperation provides the most comprehensive basis for environmental protection and pollution control (Birnie and Boyle 2002). Numerous examples of Shared Water or Joint Water Commissions exist in the region. Probably the best known is the 1987 Botswana-Mozambique-Tanzania-Zambia-Zimbabwe Agreement on an Action Plan for the Environmentally Sound Management of the Common Zambezi River System (Zambezi River System Agreement) which now also includes the Democratic Republic of Congo and is administered by the Zambezi River Basin

Commission (ZAMCOM). Such shared water agreements are flexible in nature but provide broadly for two categories of shared watercourse institutions:

- Shared Water Commissions that are essentially advisory bodies providing a forum for notification, consultation and negotiation, for coordinating responses to emergencies, for collecting data, and environmental matters including setting water quality targets and standards
- River Basin Authorities go further in that they have specific powers granted to them by parties to the shared waters agreement concerned.

Three of the four continental WIO states (Mozambique, South Africa and Tanzania) are SADC Member States and bound by the SADC Protocol. On the regional scale, the SADC Protocol, complemented at policy level by the SADC Regional Water Policy and SADC Regional Water Strategy. The SADC Protocol in Article 5 establishes the institutional set-up for the management of shared watercourses, consisting of the SADC Water Sector Organs and Shared Watercourse Institutions (SWCIs). As a framework agreement, the SADC Protocol does not contain basin-specific rules; rather it provides that watercourse states may enter into watercourse specific agreements that apply the provisions of the Protocol to that watercourse or part thereof (Article 6(3)). In line with this article of the SADC Protocol, the Incomaputo-Agreement[5] is the first comprehensive basin-wide agreement that has been drafted, Although other basins in the regions still lack such governance, it can be expected that in the long-run similar agreements will be drafted, thereby harmonising the management of shared watercourses within the framework set by the SADC Protocol (Malzbender and Earle 2007). The SADC Protocol is also notable in that it preserves the validity of existing agreements that member states have entered into prior to the entry into force of the SADC Protocol.

For WIO rivers, only four organizations: TARDA, PBWO, ZRA and KOBWA have an executive mandate, meaning that they have the authority to develop, implement and maintain joint projects and to make management decisions about those projects. They are formed specifically for some type of joint project – dam construction or operation, hydropower generation or irrigation. They do not engage in inter-state negotiations or policy formation – only operating within their clearly defined mandate as agreed by the states concerned (Malzbender and Earle 2007).

[5] Tripartite Interim Agreement between the Republic of Mozambique and the Republic of South Africa and The Kingdom of Swaziland for Co-operation on the Protection and Sustainable Utilisation of the Water Resources of the Incomati and Maputo Watercourses.

The two transboundary river basin organizations (RBOs) with an executive mandate are the Zambezi River Authority, formed between Zambia and Zimbabwe to manage and further develop the shared hydro-electric infrastructure on the Zambezi River, and the Komati Basin Water Authority, formed between South Africa and Swaziland to implement Phase 1 of the Komati River Basin Development Project. These two organisations cover transboundary rivers yet do not include all the basin states, nevertheless, these SWCIs are important as they represent a tangible example of cooperation between states – developing and managing water-related infrastructure in an effort to promote the socio-economic development which the region requires (Malzbender and Earle 2007).

2.5.7 National governance frameworks

A particular feature and potential strength is that all the countries which are subject to this study have one or more national government institution for the environment and or natural resource management. Their area of jurisdiction can be broad, such as environmental management, natural resource management or conserving biodiversity (resources and PADH), or more specific, such as regulating water pollution and waste management. But invariably a number of institutions are involved. In South Africa, for example, there is a national Department of Environmental Affairs and Tourism, a separate department of Water Affairs and Forestry, provincial departments of nature conservation in the nine provinces and parastatals such as the South African National Biodiversity Institute (SANBI) charged with the study and conservation of biodiversity. Another example is the Seychelles, where the Ministry of Environment and Natural Resources is the parent ministry to a number of sub-agencies including the Marine Park Authority, the Solid Waste and Cleaning Agency, the Seychelles Fishing Authority, and pollution control. In Tanzania there is the National Environmental Management Council (NEMC) which plays a general advisory role on similar matters.

2.6 Summary

The above chapter has outlined the geophysical characteristics that include climatic conditions and the hydrology of the WIO region. With respect to climate it has been deduced that the region is largely influenced by two distinctive systems, namely: the monsoon and subtropical regimes. The monsoon regime dominates the Somali Current Large Marine Ecosystem (SCLME), and the subtropical high-pressure system prevails in the southern part (the Agulhas Current LME or ACLME). The rainfall seasons in the WIO are strongly influenced by monsoon winds, as a result subject to wide variations in precipitation with amounts varying from over 2000 mm per year in Mozambique to as low as 300 mm per year in Somalia. On average, the island states receive more rainfall than the mainland states of eastern and southern Africa.

Within the region twelve main river basins are identified. The volume of river discharge into the Indian Ocean to a certain extent reflects the climatic attributes in the region including rainfall and temperature. Rainfall patterns in the region, thus rivers draining high rainfall areas have relatively higher discharges. Runoff decreases north to south. Thus rivers in East Africa and in Madagascar tend to carry more water than those in the south such as the Incomati. The physical base (soil and vegetation) and socio-economic characteristics also play a significant part in the hydrology of the region (see chapters 3 and 4). Runoff modification comes from the dams along the river channels that also have environmental consequences.

The WIO region comprises ten countries, of which from an ecosystem, historical and economic perspective formed more or less a cohesive geopolitical area. The governance framework for the region entails a broad spectrum of International and regional conventions, inter-governmental frameworks, agreements and institutions are central to governance in the region. Such initiatives are present across a broad range of levels from regional economic integration units at the broadest level, to specific trans-boundary commissions such as for example for the management of shared resources such as river basin management authorities, to civil society organizations at the local level.

The survey reveals that in general there tends not to be a lead agency championing the notion of integrated coastal area management, including taking the lead in designing and implementing regulations on land-based sources of marine pollution. The priority then is for each country to identify which government institution should be charged with leading regulation on marine pollution activities. In the longer term, the ideal is for each country to have a dedicated coastal agency or a coastal and marine desk/department within an existing institution such as the environmental affairs department.

3. Land Use and Water Demand

3.1 Overview

This chapter on land use and water demand lays out the groundwork for a discussion on environmental threats/issues that is undertaken in the next chapter. The discussion is framed within the socio-economic environment of the respective riparian countries since socio-economic activities occur within nation states. In this discussion, the reference to socio-economic environment is used as shorthand for political, social, cultural, financial economic, legal and institutional factors.

The chapter provides an overview of the interaction between the hydrological environment and the socio-economic activities. Direct and indirect water use through domestic use, sewerage and economic activities impact on the physical and social environment are highlighted. The fact that some of these rivers are transboundary and raise complex management arrangements as different legal, cultural, institutional and politico-economic factors apply. Other issues which complicate matters include the fact that the rivers cross different climatic zones, soil and vegetation types.

WIO states are at different stages in their political and economic development. On the macro political front it can be said that the countries are generally stable although there are questions relating to how the stable governance framework translates to the local level (Manzungu 2004). Table 3.1 shows that the majority of the countries in the region are classified as 'poor' according to the World Bank criteria and the low UNDP Human Development Index (HDI) rank. The majority of the population are in the rural areas with the exception of South Africa, which has less than half of its population resident in the rural areas.

Apart from Madagascar and Mozambique, the proportion of people in urban areas with access to improved situation is over 80%. There are also high concentrations of people in the agriculturally productive areas as indicated by the rural population density defined as the number of people per unit area of arable land.

Table 3.1: Economic and social characteristics of WIO countries

Country	Economy classification	Gross national income per capita (US$)	Population growth rate	Rural population density (no. of people per km^2)	% urban population	% of urban population with access to improved sanitation	% of coastal population	HDI rank
Kenya	Low income	360	3.3	439	35	96	8.1	146
Madagascar	Low income	230	3.0	378	31	70	36.6	149
Mozambique	Low income	200	2.8	302	34	68	39.3	170
South Africa	Low middle income	2 500	2.3	129	58	93		111
Tanzania	Low income	290	2.8	575	12	99	16.2	160

Source: UNDP 2003, World Bank 2004a, World Bank 2004b

The coastal zones of the mainland countries are currently experiencing an influx of people and expansion of economic activities such as tourism. For example population growth rates in the large coastal cities are high: Dar Es Salaam (6.7% per annum), Maputo (7.2% per annum), and Mombasa (5.0% per annum).

3.2 Tana and Athi-Sabaki

The Athi-Sabaki River has, over the past five to six decades, experienced a major increase in sediment load at loads to the estuary (van Katwijk *et al.* 1993, Kitheka *et al.* 2004a). One of the prime causes of this, is inappropriate land use in the catchment, with basin primarily attributed to intensive agriculture (both small-scale as well as and large-scale farming, including livestock and wildlife over-grazing) leading to soil erosion (van Katwijk *et al.* 1993, Fleitmann *et al.* 2007). Coupled with this has been an increase in rainfall in the basin with reduced infiltration all contributing to an increase in soil weathering and erosion (Snoussi *et al.* 2004, Kitheka *et al.* 2004a). There is evidence that this increase in sediment transport commenced at the time of British colonial settlement in the central highlands of Kenya, when there was a shift from traditional subsistence agricultural practices to more intensive land use (Champion 1933, Dunne 1974, 1975, Dunne and Ongwenyi 1976, Fleitmann *et al.* 2007). The coastal consequences of this large increase in the sediment loads in the river include the siltation of Malindi Bay, deposition of sedimentary matter and debris on beaches rendering them unappealing to tourists, and the degradation of nearby coral reefs and seagrass beds through suspended solid settlement and decreased water clarity. (Van Katwijk *et al.* 1993, Snoussi *et al.* 2004, Kitheka *et al.* 2004a, Fleitmann *et al.* 2007). Economic activities of note in the basin include agricultural, industrial and domestic uses. Total water demand in the two basins rose from 500,000 m^3 day^{-1} in 1950s to the present demand of 1.3 x 106 m^3 day^{-1} and is estimated to reach nearly 1.9 x 106 m^3 day^{-1} by 2010. Water demand is increasing at a rapid rate compared to population growth. This means that the basins will approach the point of physical water scarcity. Industrial water demand has risen to 310,000 m^3 day^{-1} from 50,000 m^3 day^{-1} in the 1960s.

Main issues related to Tana and Athi-Sabaki Basins:

Since the development of the hydropower dams on the Tana River there has been a 56% decline in sediment load to the Tana Delta (Kitheka *et al.* 2004d). This decline has led to the erosion of beaches along the Tana Delta/Ungwana Bay (Otieno and Maingi 1983, Kitheka *et al.* 2004b, Kitheka *et al.* 2004d) and a loss of wetlands and mangroves in the delta (IUCN 2003). The flow regime is highly variable, both from season to season and year on year. Some studies suggest that there is a long-term increase in runoff from the basin, but the reliability of the data cannot be confirmed (Kitheka 2004d). There has also been an increase in the use of agro-chemicals in the Tana Basin, with an expected increase in nutrient levels (Davis 2000). However, chemical water quality at the Delta has not reflected any major deterioration apart from generally high nutrient levels at the Tana Delta (Kitheka *et al.* 2004d).

There are several smallholder irrigation schemes in the Tana and Athi basins. Between them some 5,885 ha are irrigated with monthly water abstractions estimated at 58.41 m^3 per month. There are also large irrigation projects that were commissioned in the early 1950s and early 1980s. Irrigated agriculture covers some 54, 676 ha (GOK, 1992) and encompasses 30,148 ha of private development and 24 528 of Government operated schemes. In the upper catchment coffee, horticulture and floriculture irrigation are intensively practiced by private small-scale irrigation schemes. Other main crops include cut flowers, French beans, avocados and passion fruits. Total water demand in the Tana River basin is estimated to be 268 x 10^6 $m^3 yr^{-1}$, which is roughly 6% of the total annual flow. However, if all the irrigation schemes in the Tana basin were to operate at their optimum levels, total water demand would rise to the equivalent of 20% of total annual discharge.

The current level of non-irrigation water abstraction from the Tana River represents only a small portion of the total annual flow and does not really impact on the hydrology of the river. Abstraction of the Athi-Sabaki river water for irrigation is also relatively low since there are no major irrigation schemes.

In the last 50-80 years there have been significant changes in the size of forestland, which have been converted to farmland for the cultivation of tea, coffee, and maize; and also for settlement (GOK 1979-2003). This is illustrated by the fact that in the 1920s the total land area under coffee and tea was 10,000 and 5,000 ha, respectively. This has risen to 500,000 and 150,000 ha, respectively; most of the area under coffee and tea were forestland located in the high rainfall highlands of Central Kenya (Kitheka et al.).

The destruction of forests in the catchment areas of the two river basins promoted the occurrence of soil erosion. Surface runoff generated in cleared and cultivated areas, washed away loose top soil to the river channels. Further erosion is due to increased population increased the rural road network foot paths, overgrazed open fields. These represented sources of sediment load that enter into the Tana and Athi-Sabaki Rivers. This is worsened by cultivation in most cases, which is undertaken without effective soil erosion protection measures.

3.3 Pangani

Downstream of the Kirua swamps, the Pangani River turns towards the south-east and flows for about a further 220 km through the lowlands before discharging into the Indian Ocean at Pangani Town. The Mkomazi River, a major tributary of the Pangani River, rises in the South Pare Mountains and flows in a southerly direction along the eastern border of the Basin before joining the Pangani River about 15 km upstream of Korogwe. The Kalimawe Dam commands the upper 40% of the Mkomazi catchment, which includes a part of the Mkomazi Game Reserve. The Luengera River drains the catchment area between the Western and Eastern Usambara Mountains. Small hold farmers cultivate the lower slopes of the Usambara Mountains and irrigate their crops by means of a furrow system. The Luengera River joins the Pangani River downstream of Korogwe.

Main issues related to Pangani Basin:

Major water uses in the catchment incorporate agriculture, forestry and hydro power generation. Some of the small tributaries on the slopes of Mt Meru and Mt Kilimanjaro are completely drained by diversion furrows that lead to the irrigation areas. Traditional farmers also build brushwood dams to increase diversion capacities and to cause high flows to spill into the floodplains adjacent to main river channels. Between the springs and Nyumba ya Mungu Dam, the Tanzania Planting Company (TPC) abstracts water from the Kikuletwa system and from groundwater to irrigate approximately 17, 000 ha of sugarcane plantations. Increasing water use in the Kikuletwa and Ruvu catchments, which lie above the dam, has resulted in surface runoff to the Nyumba ya Mungu Dam declining sharply in the past 10-15 years. Land use practices in the catchment of the dam are thought to be contributing to substantial sediment deposits in the dam basin although no figures are available. A large portion of the yield of Nyumba ya Mungu Dam (about 24 m^3/s, or 760 million m^3/year) is reserved for hydropower generation at the dam (plant capacity 8 MW), and in the lower Pangani River at Hale (21 MW) and the new Pangani power station (66 MW).

The dam is also used to regulate in the Pangani River for abstraction to irrigation schemes and domestic supply in the central part of the Basin. These water demands outstrip the available yield of the dam, as will be shown later. The live storage capacity of the Nyumba ya Mungu Dam of 1,100 million m^3 is equivalent to about 71% of the current day mean annual runoff (MAR) of about 1, 540 million m^3. Downstream of Nyumba ya Mungu Dam, the main stem of the Pangani River flows in a southerly direction for about 120 km through the Kirua swamps. The construction of the Dam has greatly reduced the frequency and magnitude of these floods, and caused parts of the swamp to dry up although a hydrological model indicated substantial volume of water being retained by the marsh. Most of the incremental runoff in the catchment downstream of Nyumba ya Mungu Dam originates in the South Pare Mountains. Agriculture in this region and further south is mainly comprised of dryland (rainfed) sisal plantations.

3.4 Rufiji

Main issues related to Rufiji Basin:

Agriculture, fishing and various local and external commercial trades constitute the major anthropogenic pressure in the Lower Rufiji catchment. Most of these have undergone changes over time and are currently pausing significant negative effects to the future sustainability of the natural resources. Agriculture remains the main occupation of many households in the Lower Rufiji catchment with more than 90% of households in the floodplain and the delta considering it as their main occupation (Ochieng 2002).

Evolution of agriculture in the catchment has been influenced by the interplay between natural, ecological and anthropogenic factors.

Changes in social policy have also played a role in shaping the agricultural sector. While agriculture in Lower Rufiji before 1969 was totally dependent on the natural interaction between rainfall and flooding of the river, this changed as a consequence of the villagization policy that took place between 1969 and 1973. This forced most households to move from their settlements on the wet lowlands of the river valley to drier areas on the uplands, away from the flood plain. The policy had a number of negative effects. The upland farm fields are generally less fertile than the floodplain fields and are entirely dependent on rainfall (Ochieng 2002).

Consequently households, which needed to maintain farmlands on the floodplain, had to travel large distances to their fields. Due to this inconvenience, most households have small houses (*madungu*) in their floodplain farm fields, which are used as temporary homes during the farming season. The result was that the whole family stayed in the temporary houses, except children who are still in school (who stay with the farther in the village). Long time separation of families due to the division of labour impacted negatively on the social well being of households. Due to the fact that settlement on the floodplain is not permanent, pest damage is reported to have increased significantly. The lower fertility of the farm fields on the uplands, the farm fields are usually abandoned after few years. Shifting cultivation is therefore the present common type of farming on the uplands (Ochieng, 2002). This type of cultivation has a devastating effect to the conservation of biodiversity as most of the farmlands are formed from cleared forests and woodlands.

The villagization policy did not only affect the agriculture system on the floodplain. It affected the agriculture system on the delta islands: Prior to the villagization policy, the inhabitants of the delta had their rice fields in the floodplain upstream from the mangrove areas where they established temporary settlement during the farming season (Ochieng 2002). After, the farming season, they would return to their permanent settlements on the delta islands for doing other activities such as fishing, pole trade etc. The forced removal from the floodplain resulted in mangrove forest clearing as an alternative to maintain their former subsistence agriculture. Direct harvesting of natural resources does have significant impacts on the environment.

Table 3.2 presents an overview of land uses practices in the area.

Table 3.2: Scope of direct harvesting of natural resources in the Rufiji

Type of land use	Extent	Source
Firewood	62 500 tons/yr	Farm fields, woodlands, mangrove forests
Charcoal production	-	Miombo woodlands from flood plains
Timber	12 600 tons of hardwood of Dalbergia and Afzelia quanzensis	Woodlands
Poles	5 000m3/yr	Woodlands, mangroves
Hunting	-	Fire designed to scare animals

3.5 Rovuma/Ruvuma

The total current population of all districts that form part of the basin is estimated at 900, 000. This increased from approximately 700,000 in 1997. The population in the Basin is estimated to grow by approximately 2.3% per year. The Census classifies about 80% of the population in the Basin as rural. Even for 20% of the population classified as urban, many are engaged in agriculture and live in traditional houses without water or electricity. The average household size in the Basin is 4.0 people, slightly lower than the national average of 4.1.

Agricultural activities and domestic water uses dominate water consumption in the basin. Smallholder farmers account for about 90% of agricultural production. The food crops that are grown include cassava, sorghum, millet, paddy rice and maize. The main cash crop is cashew nuts. Of the 400 hectares developed for irrigation only 220 hectares are utilised (e.g. Luambala irrigation scheme, in Majune district with a total area of 6 ha). There is a surplus of water in the basin. Rehabilitation of irrigation schemes, such as Matama (160 ha in Lichinga); Unanga (100 ha in Sanga) and Chitope (0.5 ha in Ngauma) are a realistic future proposition.

3.6 Zambezi

According to Ashton et al. (2001) and Deconsult (1998) the major water uses in the basin include: urban settlements, mining, industrial, agricultural (rain fed and irrigation) and rural settlements and related economic activities.

Human activities that cause environmental impacts include land fills, sewage, domestic effluent, urban runoff, fuel loss and mining (Ashton et al. 2001). The impact of urban and industrial and rural settlements are covered in the next section. In this section only agricultural and mining activities are highlighted. Table 3.3 shows basin wide estimates of irrigable areas in the basin

Table 3.3: Irrigation potential, water requirements and irrigated areas in the Zambezi basin

Country	Irrigation potential (ha)	Gross potential irrigation water requirement		Area under irrigation (ha)
		per ha (m^3/ha per year)	total (km^3/year)	
Angola	700000	13500	9.450	2 000
Namibia	11000	5000-25000	0.255	6 142
Botswana	1080	5500	0.006	0
Zimbabwe	165400	10500	1.737	49 327
Zambia	422000	12000	5.064	41 400
Tanzania	0	11000	0.000	0
Malawi	160900	13000	2.092	28 000
Mozambique	1700000	11000	18.700	20000
Sum of countries	3160380		37.303	146 869
Total for Zambezi	3160380		37.303	

Source: FAO 1997

For the Zambezi basin as a whole, the water requirements are much less than the water availability (FAO 1997) due to water uses such as agriculture, industry, mining and hydroelectric generation (see Tables 3.4 –3.8).

Table 3-4: Overview of agriculture in the Zambezi Basin

COUNTRY	COMMENT
Angola	Agriculture is largely low intensity, subsistence farming in the basin area.
Botswana	Agriculture is largely low intensity grazing and/or subsistence farming in the basin area.
Malawi	A mix of commercial cash cropping and subsistence agriculture in the basin area. Subsistence farming uses the land very intensively leading to problems of soil erosion and loss of fertility.
Mozambique	Agriculture is largely low intensity, subsistence farming in the basin area.
Namibia	Agriculture is largely low intensity, subsistence farming in the basin area.
Tanzania	Agriculture is largely low intensity, subsistence farming in the basin area.
Zambia	A mix of commercial cash cropping and subsistence agriculture in the basin area.
Zimbabwe	A mix of extensive commercial farming and subsistence agriculture in the basin area. Subsistence farming mostly in communal areas using the land relatively intensively leading to problems of soil erosion and loss of fertility.

Source: Deconsult 1998

Table 3.5: Overview and status of industry in the Zambezi River Basin

COUNTRY	COMMENT
Angola	No large-scale industrial activity. Minimal demand for water for industrial activities and negligible risk of water pollution through contaminated effluent.
Botswana	No large-scale industrial activity. Minimal demand for water for industrial activities and negligible risk of water pollution through contaminated effluent.
Malawi	Industrial activity present and concentrated around Blantyre and Lilongwe.
Mozambique	No large-scale industrial activity. Minimal demand for water for industrial activities and negligible risk of water pollution through contaminated effluent.
Namibia	No large-scale industrial activity. Minimal demand for water for

COUNTRY	COMMENT
	industrial activities and negligible risk of water pollution through contaminated effluent.
Tanzania	No large-scale industrial activity. Minimal demand for water for industrial activities and negligible risk of water pollution through contaminated effluent.
Zambia	Industrial activity present centred on the Copper belt (Kitwe, Luanshya, Ndola, Mufulira, Chingola, Chililabombwe and Solwezi. Industries present around Lusaka and to a lesser extent Kafue, Mazabuka and Livingstone.
Zimbabwe	Industrial activity present, the major centres being Harare and Bulawayo. Industrial activity also present in Gweru, Kwe Kwe, Kadoma and Hwange.

Source: Deconsult 1998

The location, extent and magnitude of adverse environmental impacts generated from the supply of domestic water and the discharge of waste-water are closely correlated to population density (Deconsult 1998, Ashton et al. 2001).

Table 3.6: Overview and status of urban and rural water supply

Country	COMMENT
Angola	No significant urban water supply demand. Low rural population density and low water demand for domestic use in rural areas. Minimal environmental impacts from urban and rural water abstraction and effluent discharge.
Botswana	No significant urban water supply demand. Low rural population density and low water demand for domestic use in rural areas. Minimal environmental impacts from urban and rural water abstraction and effluent discharge.
Malawi	Some urban centres with a significant water supply demand. Variable population density in rural areas but in the study context a low water demand for domestic use in rural areas. Some low environmental impacts from urban water supply abstraction and effluent discharge. Minimal environmental impacts from rural water abstraction and effluent discharge.
Mozambique	No significant urban water supply demand with the exception of Tete. Low rural population density and low water demand for domestic use in rural areas. Minimal environmental impacts from urban and rural water abstraction and effluent discharge.

Country	COMMENT
Namibia	No significant urban water supply demand. Low rural population density and low water demand for domestic use in rural areas. Minimal environmental impacts from urban and rural water abstraction and effluent discharge.
Tanzania	No significant urban water supply demand. Low rural population density and low water demand for domestic use in rural areas. Minimal environmental impacts from urban and rural water abstraction and effluent discharge.
Zambia	Some urban centres with a significant water supply demand. Variable population density in rural areas but in the study context a low water demand for domestic use in rural areas. Some low environmental impacts from urban water supply abstraction and effluent discharge. Minimal environmental impacts from rural water abstraction and effluent discharge.
Zimbabwe	Some urban centres with a significant water supply demand. Variable population density in rural areas but in the study context a low water demand for domestic use in rural areas. Some low environmental impacts from urban water supply abstraction and effluent discharge. Minimal environmental impacts from rural water abstraction and effluent discharge.

Mining and mineral extraction activities are relatively widespread in the Zambezi Basin area involving both small, local scale involving traditional artisan low technology approaches and large capital intensive enterprises (Deconsult 1998, Ashton et al. 2001).

Table 3.7: Overview and status of mining in the Zambezi River Basin

COUNTRY	COMMENT
Angola	No significant development in the basin area. Sporadic occurrence of artisan workings.
Botswana	No significant development in the basin. Sporadic occurrence of artisan workings.
Malawi	Some mining activity in the Basin in Northern Malawi and Southern Malawi.
Mozambique	Some mining activity in the basin around the Tete area, mainly coal. Operations severely curtailed as a legacy of the war.

COUNTRY	COMMENT
Namibia	No significant development in the basin. Sporadic occurrence of artisan workings.
Tanzania	No significant development in the basin. Sporadic occurrence of artisan workings.
Zambia	Extensive mining activity in the Basin. The scale of operations is generally small except on the Copper belt where mining is a major industry with associated infrastructure and secondary growth.
Zimbabwe	Extensive mining activity in the Basin. The scale of operations is generally small, however, and environmental impacts comparatively localised.

Source: Deconsult 1998

The construction and operation of a large hydropower schemes will inevitably generate a multiplicity of positive and negative impacts on the natural and human environment with the area of influence (of a hydroelectric scheme in the river basin) extending from the upper limits of the reservoir to as far downstream as the Zambezi Delta, coastal and offshore zones as well as the reservoir, dam and river valley below the dam (Deconsult 1998). The potential for environmental damage needs to be balanced, though, with the recognition that major benefits also accrue from hydroelectric projects (ibid.).

Table 3.8: Overview and status of hydropower plans in the Zambezi River basin

COUNTRY	COMMENT
Angola	No existing hydropower plants in the country at this time.
Botswana	No existing hydropower plants in the country at this time.
Malawi	Three hydropower plants; Nkula, Tedzani on the Shire River and a small-scale plant (Wovwe) in the north. One plant (Kapichira) under construction on the Shire River.
Mozambique	One large-scale hydropower plant, Cahora Bassa.
Namibia	No existing hydropower plants in the country at this time.
Tanzania	No existing hydropower plants in the country at this time.
Zambia	Six hydropower plants; Victoria Falls, Kariba North Bank,

COUNTRY	COMMENT
	Kafue Gorge, Mulungushi, Lusenfwa and Lusiwasi. Capacity concentrated on the Zambezi and Kafue Rivers (97%).
Zimbabwe	Kariba South Bank utilising Lake Kariba.

Source: Deconsult 1998

3.7 Pungwe

The Pungwe River has experienced a large increase in abstraction of water for use in agriculture, urban areas and industry (Van der Zaag 2000, Hoguane *et al.* 2002). Abstraction is taking place at various points throughout the basin, including from the headwaters in Zimbabwe and the mid and lower reaches in Mozambique. No comprehensive studies have so far been carried out to assess whether there is a substantial change in the flow regime received at the Pungwe Delta (Van der Zaag 2000, Hoguane *et al.* 2002). Although no pressing issues have been identified related to the freshwater flows into the ocean, other than the fact that it could be argued that typical to the other rivers transporting sediment to the coast, there is a possible reduction of sediment volumes there. It has been reported that coastal erosion in the area does seem to be increasing (Hoguane *et al.* 2002). Table 3.9 shows the uses water is put in Zimbabwe and Mozambique.

Table 3.9: Water uses in the Pungwe basin

Zimbabwe	Sector	Mozambique
Rainfed - irrigation	Agriculture – large scale	'Farmeiros' are coming: - rainfed - irrigation
Rainfed - irrigation, e.g. Mtarazi	Agriculture – small scale	- rainfed – irrigation e.g. Gorongoza
Tea – coffee - exotic forests	Agriculture – plantations	- sugarcane - citrus
Public water supply schemes, boreholes, etc.	Rural	Individual arrangements, such as wells; public schemes in a few growth points etc.
Mutare - domestic - commercial – industrial (e.g. timber, paper)	Urban	Beira - domestic - commercial (e.g. harbour) - industrial
Nyanga NP	Parks/tourism	Gorongoza NP
Certain fish and tree species	Ecology	Mangrove and prawns

Source: Van der Zaag 2000

3.8 Limpopo

The water of the Limpopo River is used heavily used by the four basin states (Botswana, South Africa, Mozambique and Zimbabwe). Agriculture (large and small scale), mining, industry, energy production and urban water use are all significant water consumers. The large number of dams in the basin (over 40), coupled with direct abstractions, has reduced the annual flow of the river significantly (Arthurton *et al.* 2002, Louw and Gichuki 2003, Anon Mozambique 2006). The reduced flows in the lower reaches have lowered the potential for the river to absorb pollutants. Thus water quality degradation, emanating from the sources above, is a problem, with high concentrations of chromium, copper, iron and manganese found in the gills, liver, muscle and skin tissues of freshwater fish in the river (Louw and Gichuki 2003). There has also been an increase in seawater intrusion into the floodplains in Mozambique, negatively affecting agriculture (Arthurton *et al.* 2002).

The Limpopo reaches the Indian Ocean cutting through a coastal dunes belt by a narrow river mouth lacking any deltaic features. This partly indicates the prevalence of natural ocean forces over the river mouth in creating the physical environment of the narrow coastal zone whereby typical river-ocean interrelations are confined to a relatively small coastal and marine area (Louw and Gichuki 2002). The most significant direct impacts of reduced freshwater flows is the intrusion of the ocean saline marine water into the river course during high tides and the spread of sediment in the near shore sea, particularly suspended particles which on extreme floods may be transported long distances by long shore currents often many kilometres upstream. The main water uses in the basin include basin transfers, irrigation, rain fed cropping and forestry as shown in tables 3.10 (Aston *et al.,* 2001), also cite some uses to include urban settlements, mining (see table 3.11), industrial agricultural (rain fed and irrigation) and rural settlements and related economic activities.

Table 3.10 Water use in the Limpopo basin

Water use	Magnitude
Water transfers	6 schemes
Irrigation	Present: 244, 000 ha Potential: 122, 00 ha Demand exceeds: 70, 000 ha
Rainfed cropping	Crops: 234, 000 Pastures: 1, 780, 000
Forestry	455, 000

Source: CPWF (2007)

Table 3.11 Significant mining activities in the Limpopo basin

Country	Minerals
Botswana	Coal, copper, nickel, asbestos, limestone
Zimbabwe	Gold, diamond, limestone
South Africa	Coal, gold, Chrome, diamond, platinum, limestone/dolomite, dolomite
Mozambique	

Source: Ashton et al (2001)

The basin is home to large urban settlements such as Francistown, Gaborone, Pretoria (parts of), Polokwane and Johannesburg (Earle et al. 2006). The impact of these settlements on water does not just relate to the fact that they demand large quantities of water. The social and economic therein also waste, which if not managed properly can negatively water resources.

The Limpopo River Basin in Mozambique is characterized by a concentration of human population along the rivers. In the southern part of the basin high density of population is found, because of the proximity to the main national road (INGC/UEM/FEWS NET, 2003). The total population in the LRB in Mozambique is about 856 000 people, which was about 6% of the country's population. A fifth of the population lives in urban areas along the Limpopo River (INE, 1997).The density ranges from one person per km^2 (upstream Changane River) to over 1,000 people per km^2 in the Xai-Xai city. The average population density is 21.07 people per km^2 (INGC/UEM/FEWS NET, 2003). The villages in the southern part are more numerous and larger than in the rest of the Basin and progressively they reduce in size and population when moving upstream Limpopo River and its tributaries. The projections made by INE (1997) suggest a population growth in the Basin to about 1.9 million in 2010. Most of this population is expected to be concentrated in the most densely populated urban areas such as Chókwè and Xai-Xai.

Water use in Mozambique depends on availability of investment funds as exemplified by issues in the Chokwe Irrigation Scheme. The scheme is the largest irrigated area with a potential of 30,000 ha. The complete rehabilitation of the main and secondary canals is however necessary before any efficient water management can take place. Investment for rehabilitation of the Chókwè scheme is estimated at about US$45 million. There is a lot to do in terms of organization of small farmers in the family sector (water users associations). Nowadays in Chókwè irrigation scheme only 7500 ha is exploited (MADER, 2003; DNA/ARA-Sul, 2006). Further downstream a total of about 40000 ha of potential irrigated area are available (Louw and Gichuki 2003).

Other important economic activities include fishing and livestock keeping, which are carried out mainly by communities for subsistence, trading, manufacturing and service industry. The existing manufacturing activities are mainly formed by informal sector trading in food, repair workshops and light furniture and other small scale family-based enterprises (SARDC, 2003). The tourism is other important activity developed in the basin. The basin is well known for its large parks such as the Greater Limpopo Park, which involves management areas from South Africa, Zimbabwe and Mozambique. Tourism presents considerable interest in the coastal area of Gaza province, mainly in Xai-Xai because of the unique environmental features of its coastal area (SARDC 2003).

3.9 Incomati

The Incomati basin is characterised by diverse and important range of economic activities. In terms of water use per sector in the basin irrigation accounts for 51%, afforestation 35%, water transfer for power generation 14% with the balance accounted for other uses such as domestic, livestock and industry use. South Africa dominates water use across all economic and social sectors. For example 1991 irrigation data shows that out of the total the area developed for irrigation of 126 000 ha, South Africa accounted for 66%, Swaziland 11% and Mozambique 23% (Carmo Vaz and Perreira 2002). The upper Incomati basin is strategically important for South Africa due to large coal deposits and the need for water to serve as coolant in power generation systems in/or near the basin.

While the potential of irrigated area in the lower Incomati in Mozambique is estimated at 225,000 ha (Leestemaker 2000) only about 34,000 ha are currently operational; (Gomes and Famba 1999). The reduced water flow to Mozambique raises questions about whether there is enough water to develop the potential irrigated area. Availability per capita of surface water resources in Mozambique is currently about 5, 556 m^3/inhabitant/year, taking into account only the runoff generated in the country, or 1, 2000 m^3/inhabitant/year including the flows from neighbouring countries (DNA 1999). However both figures are constantly declining, on the one hand due to population growth, and on the other because of the reduction in the flows from countries upstream. Table 3.12 provides an overview of water used in the basin.

Table 3.12: Water use in the Incomati basin

Country	Area		Domestic and municipal	Irrigation	Industry	Afforestation	Livestock and game	Water transfer	Total
	Km^2	%							
South Africa	28 681	61	54,.82	593.52	21.40	472.64	8.45	131.47	1, 282.30
Swaziland	2 561	5	3.76	174.92	0.00	45.48	1.94	7.80	233.90
Mozambique	15 506	33	2.77	84.49	10.60	75.00	0.89	0.00	173.75
Total	46 748		61.35	852.93	32.00	593.12	11.28	139.27	1,689.95

3.10 Maputo

Agriculture and livestock are the main economic activities within the basin. The area under cultivation is of about 10 000 ha, of which 2.750 ha are irrigated, predominately for the cultivation of cereals (maize and rice). Furthermore, about 61,000 ha have been identified as being suitable for irrigation in the Maputo Valley. Forestry exploitation is other important activity in the basin, contributing with approximately 700 ha of commercial woodland and additional 15,000 ha were planned in 1990.

Present water demand for irrigation in the basin (Gaza Province) is about 480 million m^3 $year^{-1}$ used to develop about 40,000 ha. Irrigation accounts for 80% water use, forestry 12%, while the balance is accounted for by other uses.

3.11 Thukela

Economic activity in the basin is dominated by manufacturing. The agricultural sector is mainly based on beef and game farming in the eastern and central sub-regions. In the upper or western sub-region is found dryland agriculture and irrigation farming. Tourism (and ecotourism focussed on the Drakensburg Mountains) is growing.

There are three major dams in the Upper Thukela Catchment (Wagendrift for water supply to Estcourt, and Weened and Spioenkop for water supply to Ladysmith and regulating the Thukela River downstream and Woodstock for storage of water to the Vaal River System via the Tugela Vaal Transfer Scheme). The majority of the people in the Thukela region (74%) are rural and poor.

3.12 Betsiboka

Although there are two dams in the upstream part of the Ikopa River (a main tributary), flow regime issues seem not to be associated with dams, but rather from changing climate affecting the whole basin. Despite the absence of current data on climatic conditions in Madagascar, studies have reported increasing periods of drought, mainly in the south-western region, coupled with mostly irregular rainfall which often causes violent erosive flows downstream. Betsiboka River basin is much more affected by poor land use along its course. Bush fires and slash-and-burn practice are the main causes of the basin's degradation every year, leading to heavy sediment load transport into the Bay of Mahajanga. There is evidence that this problem began before independence in 1960. It was reported by Autrand (1997) during a study of the western coast potential for shrimp nursery, that the accretion in the Bay has reduced the water depth from 70 to 40 m. This process is thought to have transformed the former bay into a lagoon system (Autrand 1997). Nowadays, shipping activities are the first affected by the changes but the water quality may also worsen from the reduced circulation combined with the continual and direct discharge of untreated municipal wastewater. Finally, some kilometres north, at Antrema local coral reefs have also been impacted by the higher turbidity associated with the sediment load (Maharavo 2003).

3.13 Tsiribihiny, Mangoky and Fiherenana

The three south-western rivers -Tsiribihiny, Mangoky, and Fiherenana- located in a semi-arid zone of Madagascar have experienced the same problem of increasing sediment loads due to: the irregular occurrence of violent storms concentrated at the start of the rainy season; the relatively steep and long slopes in sections of the river courses; and basins in which the removal of vegetation has resulted in the erosion of topsoil. All of these impact, to varying degrees, on the mangrove ecosystem at the delta and the surrounding coral reef ecosystem, such as the Gran Recife in the Bay of Toliara, heavily impacted by siltation from the Fiherenana River. The current agricultural policies of government, encouraging and facilitating the use of chemicals and fertilisers, probably impact on the quality of freshwater downstream and subsequently on fragile nearshore ecosystems such as coral reefs. The expansion of mining and petroleum investment and activities in the country, particularly in the western part, could have a severe impact on water use and quality and should not be overlooked.

3.14 Summary

This chapter has highlighted the socio-economic environment within which land use and water demand have to be understood. The different stages of economic and social development, as reflected by selected economic indicators and human development indicators have been highlighted as an important context within which to understand land use and water demand. Given that the land use and water demand in the individual countries are likely to be affected by the socio-economic environment, a country like South Africa with a strong economy and diversified economic base (in the form of a strong manufacturing base, mining and agriculture) will continue to require more water whose use will have significant impacts on the environment. This picture will continue to change as a consequence of economic and social developments as other countries embark on development. One can expect increasing water demand and impact on the environment.

A common problem in the WIO region is poor land use practices (e.g. over-grazing, deforestation) which are often aggravated by increased population pressure. Poor land use practices can lead to problems of large-scale soil erosion (and resulting increase in sediment load), which may severely impact river floodplains. Combined with reduced or significantly altered flows, detrimental effects can be felt at the estuaries (Dunne and Ongwenyi 1976, Kitheka *et al.* 2004a, Turpie 2006). Natural phenomena such as climatic extremes (violent rainfall) coupled with slash-and-burn practices to clear land for grazing is a common cause of wide-scale soil erosion. An example is the western sedimentary zone of Madagascar, with resulting dramatic increases in sediment load in affected rivers. Salomon (1987) measured the average rate of specific degradation of south-western Malagasy river basins reporting 3,000 tons/km^2/yr, a value significantly higher than those of other major rivers.

Tables 3.13 and 3.14 present the overview of important land and water uses in the individual basins. Agriculture is the main land use sector in the basin, which consequently places water demand for irrigation, though in most basins rain-fed agriculture, is more prevalent. The other sectors include forestry, urban/rural settlements, mining and landfill. Domestic water supply is the second main water user after agriculture in the region.

Agricultural activities in the countries of the WIO region are increasing and are becoming more industrialised. With this comes the risk of increased soil erosion and use of agro-chemicals. Even without substantial scientific evidence of existing impacts, it can be expected that marine pollution risks associated with agricultural activities (e.g. high suspend solid, nutrient and persistent organic pollutant loads) may well increase in coming years, unless appropriate and environmentally-sustainable agricultural practices are promoted within the large river basins discharging into the WIO region, thereby following the precautionary approach.

Table 3.13: Overview of important land use in the basins

Basin	Agriculture	Forestry	Settlements	Mining	Landfills
Tana & Athi-Sabaki	√	deforestation			
Pangani	√	Afforestation	√		
Rufiji	√		√		
Rovuma	√				
Zambezi	√			√	√
Pungwe	√				
Limpopo	√		√	√	
Incomati	√	Afforestaton			
Maputo	√	Afforestation			
Thukela	√				
Betsiboka					

Table 3.14: Overview of water demand in the basin

Basin	Irrigation	Fisheries	Forestry	hydropower	Domestic	industry	mining	IBTS	Animal Watering
Tana	√				√	√		√	
Pangani	√		√	√	√				
Rufiji	√	√			√				
Rovuma	√				√				
Zambezi	√			√	√	√	√	√	
Pungwe	√				√			√	
Limpopo	√	√	√		√	√	√		√
Incomati	√		√	√	√	√		√	√
Maputo	√		√		√				√
Thukela	√				√	√		√	√
Betsiboka					√				

Table 3.15 shows intensity of water use across the basins. The reference to significant or non significant/negligible refers to the degree to which a particular land use has impacts on the water environment either in terms of quantity or quality. It is also important to highlight the fact that the table shows relative and not absolute weightings. To this end it does not mean that the designation of significant of a land use in any two or more basins means that the impacts are same –rather it means the land use is significant within the basins.

Table 3.15: Summary of water uses in the various river basins

Basin	MAJOR LAND/WATER USES						
	Agricultural	Industrial/mining	Power generation	Deforestation/forestry	Tourism	Livestock	Domestic
Athi-Sabaki	S	S	NS	S	NS	S	NS
Tana	S	S	S	S	NS	S	NS
Rufjii	S	NS	NS	S	NS	NS	NS
Pangani	S	NS	S	S	NS	NS	NS
Ruvuma/Rovuma	S	NS	NS	NS	NS	Ns	NS
Zambezi	S	S	S	S	P	P	S
Maputo	S	NS	NS	NS	NS	NS	S
Incomati	S	S	S	S	P	P	S
Limpopo	S	S	S	S	P	P	S
Pungwe	S	NS	NS	NS	NS	NS	S
Thukela	S	S	S	S	P		S
Betsiboka							

Source: Based on Ashton et al., 2001 AUFab, Chenje and Johnson 1996

S =significant NS =not significant/negligible

The intensity of land and water use in the various basins within the region differs significantly depending on the economic practices and livelihoods. In view of the economic sectors as presented in tables 3.13 and 3.14, in some river basins, almost all the sectors are competing for the available land and water resources, resulting in the intensive use of these resources. Incomati, Limpopo, Thukela and Zambezi are clear examples of such river basins. Table 3.16 shows the basins categorised in “very intensive use”, “intensive use”, and “moderate use”.

Table 3.16 Intensity of land and water use in the various basins

Very Intensive use	Intensive use	Moderate use
Incomati	Athi-Sabaki	Maputo
Limpopo	Rufiji	Rovuma
Thukela	Pangani	Pungwe
Zambezi	Tana	Betsiboka

4.0 Environmental Issues

4.1 Overview

After presenting the climate and hydrology of the river basins in chapter 2, and providing an overview of land use and water demand in chapter 3, this chapter turns to the question of the status of environmental issues and threats. The chapter presents an overview of environmental issues/threats at the national level because environmental phenomena in any river basin are subject to the social and economic characteristics of the nations within which they occur. In this endeavour, selected indicators are used to illustrate the points across the main social and economic sectors. The national overview is followed by description at the individual basin level before raising the main summary and conclusions.

In this chapter the focus is on environmental problems relating to:

- Stream flow changes
- Point source and non-point sources of pollution
- Deforestation and catchment degradation
- Impacts of source of energy in terms of whether the main source is clean or not.

As a background Table 4.1 shows the characteristics of freshwater use in the different countries. Data in the table indicate that agriculture is the largest use of water, a common phenomenon throughout the world. The proportion of water ascribed to industry use belies the state of industrialisation among the countries. It is generally low with the exception of South Africa.

Table 4.1 Characteristics of freshwater use in the WIO region

Country	% of total resources	% for agriculture	% for industry	% for domestic
Kenya	6.6	76	4	20
Madagascar	4.8	99	-	1
Mozambique	0.3	89	2	9
South Africa	26.6	72	11	17
Tanzania	1.3	89	2	9

Source: World Bank (2004a)

Seven common factors contribute to environmental problems related to river-coast interaction in the WIO region:

- *Climate change and natural processes* – Climate change and natural events to an important extent influence river flows, turbidity and sediment transport. For example, Mozambique has in recent years had several severe floods impacting on the floodplain and delta in the lower reaches of the Zambezi and Limpopo rivers. Most of the region is characterised by large spatial as well as temporal variations in rainfall. Year-on-year variation around the long term norm for various parts of the region is as high as 30–35 % (Earle and Malzbender 2007). This natural climatic variability is exacerbated by overall climate change. Temperature increases of between two and six degrees by the end of the 21st Century is predicted by the IPCC (2005) for much of the region, though the exact impact is more difficult to predict, with some areas experiencing an increase while others a decrease in rainfall. What seems likely is that there will be an increase in extreme events such as floods and droughts following on from each other (UNEP 2005). This is likely to increase the stress on already compromised river systems in the region by increasing soil erosion and sedimentation and, in places, increasing pollution concentrations where average water volumes decline. Reduced freshwater volumes to the coast in times of drought poses a considerable threat to river-coastal processes.
- *Economic growth* - Increased demands for limited water resources due to economic growth in the region results in growing competition over the resource between different sectors and the construction of more dams on rivers. Over the past half century, countries in the WIO region have experienced high levels of economic development, with a commensurate increase in water use in river basins for industry, mining, urban development, agriculture and energy production (TPTC 2001, Arthurton *et al.* 2002, Van der Zaag and Carmo Vaz 2003, Hoguane 2008). This trend is likely to continue with several countries in the region already experiencing electricity shortages due to the increase in demand from industrial users. The response in South Africa has been to plan the construction of new power stations (such as the dry cooled Medupi plant in the Limpopo River basin). With electricity production currently the largest user of water in that country, and forecast to grow, this will likely lead to increased demands for water on the resources of the Limpopo and Incomati rivers.
- *Population pressure* – The increased demand for water resources by growing populations can change river systems, irreversibly. For example, in the Pangani River basin (Tanzania) where increased water use of the Luengera and Mkomazi rivers, which were historically perennial, has now led to only seasonal flow (PBWO/IUCN 2007). All of the countries in the region have experienced medium to high rates of

overall population growth, which in the context of a finite supply of water resources, equates to a greater demands on existing supplies (Hirji *et al.* 2002).

- *Poverty and inequality* – Due to limited resources, people engage in unsustainable land-use practices, such as over-stocking of cattle leading to over-grazing and therefore increased runoff of nutrients and soil erosion. Other harmful practices are the inefficient application of fertilisers and use of (often cheap) harmful pesticides leading to compromised water quality. Poverty and inequality is also at the base of large-scale deforestation for fuel wood and building materials in many areas at the coast, which is at the root of increased soil erosion and sediment load to rivers. Poor sanitation and lack of waste water treatment infrastructure can lead to the contamination of coastal waters and therefore living resources on which many poor communities subsist.
- *Inappropriate governance* - The lack of inter-sectoral coordination, notably with little or no involvement of different water use sectors, with different sets of requirements in the management of the resource, leads to the misuse of the resource. This is widespread in the region, often with no, or inadequate, intervention and governing regulatory instruments. Stakeholder views, knowledge and interests are also limited. The lack of information and data (in some areas) of the nature, causes and impacts of environmental problems, and weakly enforced legislation, compounded by the lack of harmonised legal and institutional frameworks for the management of transboundary rivers has caused the deterioration of rivers and adjacent coastal areas. Fortunately, these issues are increasingly being addressed, with a more detailed analysis of governance related issues presented in Chapter 5, Section (5.3.6) with particular relevance to river basin management structures.
- *Inadequate knowledge and awareness* – Includes two important factors:
    - Shortcomings in information and data of the nature, causes and impacts of certain environmental problems. For example, in the Pangani River the melting of glaciers on Mount Kilimanjaro has increased river flow during certain periods in some of the tributaries, making it difficult to determine whether increased water abstraction has had an impact on overall natural flow conditions (PBWO/IUCN, 2007).
    - Lack of awareness of stakeholders of the impact of their activities on other stakeholders and the ecosystem as a whole. For instance, in the Incomati River water is abstracted for cooling power stations and for use in irrigated agriculture, with the result that there is an increase in salt water intrusion from the marine environment into previously freshwater reaches of river systems (TPTC, 2001).

- *Inadequate financial resources* and human capital– There is limited financial and human resource capacity for effective implementation and monitoring of agreements and comprehensive water management regimes.

The impacts of changes in river flow and sediment loads on the WIO coastal and marine environment results in physical alteration and destruction of habitats, the degeneration of water quality or a combination of these issues.

The impacts on environment have to be understood not just in terms of the quantity but the efficiency of production (see Table 4.2).

Table 4.2 Selected environmental indicators in the WIO region

Country	Fertiliser consumption1	Average annual deforestation2	Source of electricity3		Water pollution4	CO2 emmissions5
			Coal	Hydro		
Kenya	322	0.5	-	54.7	0.25	0.3
Madagascar	27	0.2	-	-	-	0.1
Mozambique	40	0.9	-	99.5	0.31	0.1
South Africa	510	0.1	94.0	1.0	0.17	7.4
Tanzania	56	0.2	3.2	91.7	0.25	0.1

Source: World Bank (2004a)

From Table 4.2 a number of issues can be highlighted:

- With the exception of South Africa, WIO countries rely on what can be called clean energy in the form of hydroelectricity.
- Since there was not enough data on emissions of nitrates and phosphates into the ecosystem not much can be said about how fertiliser use contributes to pollution. It is not just the amount of fertiliser used; it is the efficiency of use that is important.
- Deforestation has a multitude of consequences on the environment including erosion and loss of biodiversity and presents a paradox in that the quest for deriving utility from forestry resources results in the very resources and other being unavailable.

There are also problems in the social sectors. For example, increasing pollution from domestic sewage and solid waste is a major challenge in some coastal cities (e.g. Mombasa, Dar Es Salaam, Maputo, etc) where a large proportion of the population uses pit latrines. Domestic sewerage system serves a small proportion of the population. Only a small proportion of urban areas are served by septic tanks and soak pits. This situation is causing contamination of ground-water sources leading to water-borne diseases, which include cholera, dysentery, schistosomiasis, infectious hepatitis, typhoid and malaria in coastal towns.

4.2. Tana and Athl-Sabaki basins

Table 4.3 shows that due to various processes, the nutrients levels in the Tana and Athi-Sabaki estuaries are high. The major threat on water quality has been fertilizer residues (nutrients) from intensively cultivated regions of Central Kenya highlands where coffee and tea cultivation dominates. However, the threshold chemical contamination levels of both Tana and Athi-Sabaki rivers have not been attained. Sediments are also important environmental problem since soil erosion within the basin is a significant problem.

Table 4.3: Current and future environmental threats in the Tana and Athi-Sabaki basins

Environmental issues	Cause	Impact/consequence	Extend
Increased sediments	• Poor land use practices • Deforestation • Urban development	• Limits use of port facilities • Reduces the aesthetic and recreational values of Malindi beaches • Degradation of coral reefs, sea grass beds off the shore	• Malindi bay • Malindi beaches • Marine national park
Altered fresh water flow	• Wastewater and storm water runoff from urban settlements • Hydrological variability	• High flow variability • Increased flash of flood events dues to reduced percolation of rainfall	Malindi bay
Water quality degradation	Poor land use practices	• Increased turbidity of water • Impacts on coastal habitats particularly coral reef ecosystem	

4.3 Pangani

According to the Pangani State of the Basin Report the "main causes of (Pangani) river degradation are: changes to the flow regime; changes to the channel and riverbed, including the extent of inundated areas such as floodplains; changes to water quality due to pollution; and the presence of alien plants and animals" (PBWO/IUCN, 2007). In the Pangani basin, power production at the Nyumba ya Mungu Dam relies on storage of water during rainy seasons and a constant release of water through the turbines (PBWO/IUCN, 2007). Regulation at the dam also ensures a relatively even flow through the year to the downstream power stations at Hale and New Pangani. The Nyumba ya Mungu Dam on the Pangani River and Kalimawe Dam on the Mkomazi River have had the effect of smoothing-evening out the natural seasonal and inter-annual flow regimes experienced at the estuary, significantly changing the natural hydrographic pattern (Lugeiyamu 2002). In the dry season, the low base flows are still present due to constant dam releases, but any higher flows are withheld by the dams. In the wet season, large floods still move down the system but smaller floods and a proportion of the low flows are trapped by the dams between floods. Thus, the flow volumes are lower than natural (PBWO/IUCN 2007). The quality of the river water generally deteriorates from upstream to downstream (Lugeiyamu 2002). Most of the lower reaches of the river are classified by the State of the Basin Report as being *"largely modified[6]"* for parameters such as water quality, stream morphology and aquatic life. Poor quality is mostly related to increased levels of dissolved salts, nutrients, faecal coliforms, decaying organic material and turbidity in various parts of the system (PBWO/IUCN 2007). Dissolved oxygen levels in the estuary are very low, especially in the upper reaches before the diluting effect of seawater plays a role.

Three sets of environmental problems are identified in the basin relating to:

- The disturbance of upstream water source areas as a consequence of poor management of agricultural land as well as expansion into forest areas. The disturbances result in high sediment loads that impacts downstream waters, river channels, irrigation schemes and reservoirs, blanket wetlands and increase turbidity of rivers and lakes and increase in flash floods. Ground water recharge areas are threatened by inadequate land management and uncontrolled development.
- Increased abstraction of water for irrigation and other uses can seriously affect wetlands particularly in the Usangu plain, National Parks and estuarine areas. Diversions taking place outside Tanzania particularly the Pangani basin can result with transboundary problems to Tanzania (World Bank/Ministry of Water 2006).
- The discharge of industrial effluents may be a serious emerging issue in most river basins. There is little systematic water quality monitoring data available to verify the extent of the problem. Agro-chemical pollution and gold mining in several river basins are suspected to be cause land degradation and localized mercury pollution, respectively although lack of data prevents the extent of the problem being known (World Bank/Ministry of water 2006). Table 4.4 presents a summary of environmental problems in the basin.

[6] Ecological state: Severe modification with major disruptions in ecosystem functioning; mostly tolerant species remaining, often to pest proportions; alien species common; plants and animals may be diseased (PBWO/IUCN 2007).

Table 4.4: Current and future environmental threats in the Pangani River Basin

Environmental issue Current	Causes	Extent	Consequences
Competition over water between irrigators, and urban use and irrigators	Rapid population growth and poor enforcement of water licenses	Along length of rivers	Conflicts and limitations on production
Inadequate water flows	Low water levels in rivers due to illegal and excessive abstractions	Industrial parts and farming areas	Loss of power to industry and inefficiency of lower Moshi irrigation scheme.
Drying of Kirua Swamp	Problems in Reservoir operational procedures	Kirua Swamp	Loss of biodiversity
Reduction in size and degradation of Lake Jipe and Chala wetlands and water access issues for farmers	Irrigation abstractions in Kenya and nutrient enriched flows & reduced water availability from Mt. Kilimanjaro	Lake Jipe and Chala wetlands	Weed infestation and reduction in livelihoods for riparian farmers
Land degradation	Poor land management practices	Upper basin	Loss of valuable soils, downstream siltation problems
Sustainability of water resources affected by loss of forests due to illegal cutting, grazing and bush fires	Expansion of dry- land agriculture from population growth	Upper basin and slopes of eastern arc mountains	Increased flood risk, reduced water availability.
Reduction in snowpack affecting water sources	Climate change	Mt. Kilimanjaro	Affect inflow to rivers and underground reserves
Pollution from sisal, mining industrial discharges and urban sewage	Untreated effluents and urban sewage	Downstream of towns and agri-industrial sites in upper basin	Downstream loss of aquatic life and health problems
Ground water draw down	Lack of understanding of drillers and poor enforcement of drilling licenses	Localized to specific aquifers mainly in the upper basin	Diminution of long-term resource
Future			
Potential water quality issues			Health problems due to Mercury pollution

Source: World Bank/Ministry of Water (2006)

4.4 Rufiji

The Rufiji River, like the Athi-Sabaki River in Kenya, is one of the last undammed rivers (on the main stem) in the region (Shaghude 2004). At present there is some degree of water quality degradation in the Delta region, mainly as a result of DDT applied by rice farmers to combat freshwater crab damage to seedlings (Kulindwa *et al.* 2001) though contamination is at a low levels and seems to be locally confined. Nutrient flows from agricultural activities upstream in areas around Mbeya and Iringa are high, but again, most of this is broken down or absorbed by the ecosystem prior to it reaching the delta (Mwalyosi 2004). The flow of water and sediment also appears to be stable, with no significant changes noted. Building of dams, such as the one proposed at Stiegler's Gorge, would result in the main impact of trapping of sediments being transported downstream – and preventing them from reaching the delta. A reduced volume of the fine sediments translates into a reduction in the average supply of nutrients to the floodplain and delta. This is expected to have significant consequences to agriculture and the deltaic and offshore ecology (Shaghude 2004). Table 4.5 presents a summary of the environmental issues in the basin.

Table 4.5: Current and future environmental threats in the Rufiji river basin

Environmental issue current	Causes	Extent	Consequences
Water allocation issues	Expansion of upstream irrigation areas	Immediately downstream in the Usangu basin	Conflicts among irrigators, pastoralists, environment, national park & hydropower
Loss of flows to Ruaha National Park during dry season	Upstream irrigation including rice farms.	Ruaha National Park	Diminution of biodiversity and loss of tourism income
Changes inflow pattern of Rufiji delta	Occasional floods	Rufiji delta	Flooding in some places and salt water intrusion
Agrochemical pollution from irrigation	Certain reach Usangu wetland & Ruaha NP	Downstream of Usangu basin	Health issues
Water pollution issues	Agro-industries (pulp mill, bark processing sugar mill)	Downstream of industrial enterprises and irrigation areas	Health effects
Rufiji hydropower development	-	-	Potential water allocation issue between hydropower & environment
Agro-industries increase in the basin	-	-	Potential deterioration of water quality

Stigler's Gorge hydropower development	-	-	Potential water allocation issues for lower Rufiji River water users & the environment
Increase in tourism in the lower reaches	-	-	Pressure on environmental flow allocations.

Source: World Bank/Ministry of Water 2006

4.5 Rovuma/Ruvuma

The hydrology of the Ruvuma River has not been systematically studied, thus little is known of changes in flow rates or quantities or about changes to sediment load from natural (Francis *et al.* 2002, DNA 2004, Lerise 2006). Floods and a high sediment load seem to be a natural part of the natural regime, with no evidence of anthropogenic drivers (DNA 2004). The remoteness of the river and relatively low population densities in the basin has meant that some of the best preserved mangrove forests along the coastline are found in the estuary (Kyewalyanga 2004).

The Rovuma_estuary dominates the middle part of the Tanzania-Mozambique Cross Border Coastline. In general the coastline is made up of a stable basement with deep sheltered bays with potential for fishing and sea sports. The coastline of Mtwara Region and Cabo Delgado province extents for about 200 km, the estuary covers 15 % of the coastline. While the other parts of the beach are sand the estuary is muddy tropical area, which is suitable for mangrove growth. In the Mozambican side of the Ruvuma estuary there is a protected area in form of marine parks, the Quirimba National Park. Environmental problems in the Ruvuma basin are related to natural (flooding) and agricultural factors (Table 4.6).

Table 4.6: Current and future environmental threats in the Ruvuma river basin

Environmental issue current	Causes	Consequences
Flooding along Ruvuma river	Wet season floods are natural but it may be exacerbated by land clearance	Loss of crops & threats to life
High sediment loads in rivers during rainy season	May be poor agricultural practices or natural	Cost of water treatment & loss of habitat
Some areas have ground water with deficiency in Fe and others with high Fe contents	Natural occurrence	Health effects
Possible agro-chemical contamination of surface water during rainy season	Poor education to farmers	Health effects
Future		
Flooding along rivers and high sediment loads during rainy season		Water problems during dry season and pollution problems.

(Source: World Bank/ministry of water 2006).

4.6 Zambezi

Environmental threats to water resources in the Zambezi basin can broadly be categorised into stream flow reduction/runoff modification and pollution of water resources from a variety of sources. In this paragraph only the latter is covered since the former has been dealt with in chapter 3. The account on pollution is based on the IMERCSA Zambezi (1999) study. Environmental threats in the basin encompass land and water resources as well as the atmosphere. However the impacts on soils, vegetation and water have not been fully studied. Pollution in the basin can either be point or non-point source. Point sources of pollution in the basin relates to: sewage effluent, industrialisation, power generation and mining.

The construction of the Kariba and the Cahora- Bassa dams has had the dual impact on the Zambezi Delta of reducing sediment load and altering the seasonal variability of flow (ZRA 1998, Beilfuss 1999, Chenje 2000, Brown and King 2002, Turpie 2006). According to a study by Gammelsrød (1996), as cited by the ZRA (1998) report, “in the case of the Zambezi River the construction of Cahora Bassa Dam in Mozambique has had a significant impact on fisheries, particularly along the Sofala Bank at the River mouth”. This has bearing to on populations of the shrimp Fenneropenaeus indicus (previously called Penaeus indicus), for example, where there is a close relationship between river runoff and abundance found on the muddy Sofala Bank. Regulation of river flow has two main impacts on this shrimp: (a) increased runoff during the dry season that is likely to set up currents heading offshore strong enough to prevent the larvae from entering nursery areas and (b) after having developed to a juvenile stage lower flows resulting in less flushing of nursery areas, a strong rainy season runoff facilitates high levels of freshwater thereby decreasing recruitment to the fisheries - because higher runoff flushes a larger area and creates a stronger of young juveniles to the offshore current (fishery (ZRA 1998).

The economic losses from reduced fisheries landings, due to the reduction in nutrients entering the Indian Ocean at the Sofala Bank fishery (Arthurton 2002), following alterations to the Zambezi River freshwater flows has been estimated at between 10 and 20 million USD (Turpie 2006). In addition, there has also been a large reduction in the extent of the mangrove forests, due to desiccation following reduced freshwater flows (Beilfuss 1999) while the reduced sediment load has led to increased coastal erosion.

Sewage effluent, industrialisation and power generation are directly related to urbanisation, identified as the biggest pollution threat in the basin. Sewage effluent is a problem because of inadequate treatment facilities. The following are highlights of some major pollution problems:

- Livingstone in Zambia with a population of 100,000 which happens to be closest and largest settlement to the river used to discharge raw sewage into the Zambezi prior to 1995 and is still characterised by limited discharge.
- Victoria Falls in Zimbabwe with a population of 30,000 discharges 8,000m^3 of wastewater, overloaded and broken down facilities discharge into river.
- Chitungwiza in Zimbabwe with a population of 350,000 discharges semi-treated effluent into Manyame River, which is a tributary of the Zambezi River[7].
- Kariba and Kasane exceeded permissible Zimbabwean standards of phosphate and nitrogen levels in the final effluent which was also true for Victoria Falls, Livingstone.

Industrial pollutants find way into the environment and are found in the highly urbanised part of the basin that includes Manyame, Kafue and Kwekwe/Sanyati systems. Industrial activities include in the basin include mining, chemical fertiliser, and textile manufacturing. Over 93,000 tonnes of industrial waste are produced annually.

[7] Discharging semi- or partially treated effluent into water bodies causes eutrophication because of high nitrogen and phosphate levels

Mining causes water acidification and discharge of toxic elements such as arsenic mercury, cadmium and lead. Table 4.7 shows the overview of the mining activities in the basin.

Table 4.7 Significant mining activities in the Zambezi basin

Country	Minerals
Botswana	Coal
Mozambique	Coal, gold
Zambia	Copper, amethyst, cobalt, limestone, coal
Zimbabwe	Coal, cobalt, gold, diamond, nickel

Source: Ashton et al (2001)

4.7 Pungwe

The Pungwe basin is generally considered to be pristine (Van der Zaag 2000). The main environmental issue relates to the water transferred from the basin in Zimbabwe. However, Van der Zaag (2000) and Hunguane et al. 2002 point out that increased water abstraction upstream of the estuary has lead to a reduction in stream flow and increase in coastal erosion. Another key issue in this basin pointed out is decrease in sediments load, which impacts directly through increased coastal erosion leading to loss of land and valuable biodiversity. Future developments in the basin can exacerbate the above mentioned threads on the basin.

4.8 Limpopo

Environmental problems in the Limpopo Basin are a combination of excessive water abstractions upstream and the resultant pollution. The over-utilization of water resources and pollution arising from high-density urban settlements, river regulation, upstream mining activities and other industrial development are seen as the main activities leading to the continuous deterioration of the environment downstream (IWMI/ARC 2003). Recent studies in the basin by DNA (1999) and Ashton *et al.* (2001) indicated that throughout the length of the Limpopo, the main water quality problems and threats include: increasing salinity; discharge of untreated or partially treated domestic and industrial effluents; declining of river flows due to escalating demands for water; and discharge of untreated loads from upstream mining activities.

The Elephants River is a clear example of pollution source as a consequence of mining activities, where heavy metals, such as Copper (Cu), Nickel (Ni) and Iron (Fe) were found in the gills, liver, muscle and skin of sampled fish. These metals derive from different industrial productive activities since there in no wastewater treatment system (Louw and Gichuki 2003).

Erosion and salinization are of great concern in the basin, and constitutes the great sources of diffuse loads and pollutants to the river. The basin shows relatively advanced eroded conditions, and often shows younger and shallower soils as compared to less eroded surrounding areas (FAO-SAFR 2004). There has been no regular monitoring of sediment loads within the Lower Limpopo Basin since 1981. However, measurements of suspended sediment have been made at some hydrometric stations in the past. Observations made at Xai-Xai between 1973 and 1978 showed that the highest mean load concentration of suspended sediments was 9680 gm^{-3} and the minimum was 80 gm^{-3} (Louw and Gichuki 2003). Using these figures, it has been estimated that the total sediment transport of the Limpopo River is of the order of 10 million $tons.year^{-1}$. There is no current information on quantification of the effects of either dam construction or agricultural/mining activities on sediment transport within the Lower Limpopo Basin. However, it is speculated that increased soil erosion resulting from mining activities and agriculture within the South African part of the Elephants River catchment may be increasing the sedimentation within the Massingir Reservoir and so reducing its live storage (Louw and Gichuki 2003).

In Mozambique the main sources of pollution to the Limpopo River include, among others, the intense agricultural activities in the Chókwè region (use of fertilizers and pesticides) worsened by the deficient drainage of water in the Chókwè irrigation system. In addition, high loads of salts and other contaminants are likely to drain into the river because of the salty geologic formation of the river bed (e.g. Changane River) and of erosion and low permeability of the predominant soils (Mananga) (DNA/ARA-Sul 2006). Non-point domestic effluent discharges from rural and small towns along the river and tributaries, salt intrusion and mineralization of waters due to reduced flows are other sources of pollution. Table 4.8 provides an overview of factors affecting water quality in the Mozambican section.

Table 4.8: Factors contributing to spatio-temporal variability of water quality in the Limpopo River Basin in Mozambique

Natural dynamics
▪ Season (weather) flow velocity due to low and erratic rainfall, high temperatures, high evapotranspiration ▪ River drainage over an arid zone resulting in high mineralization ▪ Space: reduced flow velocity due to low topographical gradient, long distance from the sources of pollution in some cases, transport of sediments ▪ Natural conditions along the river on the neighbouring countries (e.g. geology, climate) ▪ Salt intrusion due to high tides (± 55 km upstream river mouth).
Human impacts
Physical and chemical disturbances: ▪ Diffuse discharge of untreated urban and small enterprises wastewaters ▪ Discharge of sewer systems (e.g. Chókwè and Xai-Xai) ▪ Discharge of untreated wastewater from small scale industries. Diffuse sources of pollution due to: ▪ Agriculture (fertilizers and pesticides) ▪ Soil erosion and sedimentation ▪ Drainage of saline soils at Chókwè irrigation scheme ▪ High livestock population (manure) ▪ Mining activities. Structural and morphological is divided into: ▪ Upstream water quantity management (weirs, dams, artificial embankments) ▪ Physical pollution during rainy season (wood debris).

The Massingir dam had been pointed as a potential physical infrastructure that would worsen the water quality in the Limpopo River because of possible drainage of high salted bottom layers of water. Pilot studies by DNA/ARA-Sul (2006) proved that the drained water has a low concentration of salts. Reduction of flows in the river the water quality may deteriorate. Altogether these pollutants and loads reduce the water availability (quality) further downstream the basin, interfering with vital and legitimate water uses such as drinking, aquatic wildlife, recreation, irrigation and industrial use. The degradation of wetlands, coastal ecosystems, Indian Ocean bottom morphology and mangroves vegetation at the Limpopo banks are other risks that may derive from the increased pollution of the

Limpopo water or by reduction of its flows (Louw and Gichuki 2003). All these problems associated with the cyclic drought and flush floods worsen the livelihood in Mozambique.

4.9 Incomati

One of the overriding issue in the Incomati River Basin is the "Reduction in stream flow", which (according to Hoguane *et al.,* 2002) should be better termed **"**Modification of stream flow", to reflect both the drought and flood situations. Modification of stream flow is considered as the main issue because it contributes to other issues:

- Pollution of existing supplies, since water shortage contributes for rapid deterioration of water quality, as in such a case there is high risk for recycling water, and further, the flushing time of the water is longer
- Modification of ecosystems and ecotones, since the reduction in river flow may cause chronic erosion/accretion along the coast and salt intrusion in the estuaries
- This in turn may contribute to the reduction in availability of the natural living resources (both fauna and flora) further, floods cause severe
- damages to the habitats and to the infra-structures (Hoguane *et al.* 2002 Anon 1998).

Reduced streamflow is an issue because of water shortage manly caused by the increased demand for agriculture, urban and industrial developments. The mean annual irrigation water requirements for actual developed areas within the Incomati River Basin is estimated as 1125.9 Mm^3, and distributed as follows: Mozambique (280.3), South Africa (669.6) and Swaziland (174.9). There are plans to increase the irrigated areas in South Africa, Swaziland and Mozambique (Van der Zaag and Carmo Vaz 2003, Carmo Vaz and Perreira 2002).
The population growth and the increase in the urban area and in industry, demand more water than the river basin can supply, and consequently more dams are being constructed and water from the Incomati is taken and discharge into other basins.

As already noted water shortage has also resulted in deterioration of water quality, resulting in pollution and consequent occurrence of water born diseases. For example bacteria *Vibrio parahaemolyticus* and *Vibrio mimicus* were found in clams in the Incomati River mouth (Fernandes 1996, Anon 1998). Reduction in river runoff causes salt intrusion and sediment deficit that extends over 80 km and extends about 40 km upstream. The runoff required to keep the salt intrusion below 20 km upstream is 35 $m^3 s^{-1}$ against the 2 $m^3 s^{-1}$, set in the Piggs Peak Agreement.

Floods occur in the Lower Incomati Basin at irregular Intervals, with impacts on agriculture, damage to infrastructure and loss of life. The most devastating flood occurred in the year

2000 (Van Ogtrop *et al.* 2005, Carmo Vaz and Lopes Pereira 2000, Savenije H. and I. Vaz 1984).

The Incomati River, because is shared between the three countries, is prone to transboundary conflicts (Anon 1998). For instance the existing allocation of water to Mozambique is considered by the government to be too low, raising the sensitive issue of international equity (Anon 2001). During the Apartheid regime dams were used to fight Mozambique government creating either astronomical floods or droughts (Van der Zaag and Carmo Vaz 2003, Carmo Vaz and Lopes Pereira 2000, Savenije H. and I. Vaz 1984).

Water demand is continuously increasing and has by far surpassed the water available in the Incomati River basin. There are many stakeholders with different interests and water requirements, coupled with huge differences in terms of their culture, habits, technical and scientific knowledge, and economic development. Thus, local and transboundary conflicts are eminent if the issues of concern for each and every one involved are not adequately addressed. Hence, there is an urgent need to building consensus and a shared vision on the river's future development, observing the basic principles of equity and sustainability in the water allocation and management of the river basin.

4.10 Maputo

The Maputo River basin crosses an area of very rich bio-diversity, having been recognized as such by UNEP and included as one of the world's conservation stream areas, thus its preservation is of extreme importance. However, the use of the River is limited at its mouth by the intrusion of seawater. Intrusion is greatest when flows are low, that is during the dry season. For a flow of 21 m^3/s, the river water at high tide is unsuitable for irrigation 30 km from the mouth. In dry year with flow of 12 m^3/s (P=80%) saline water extends 40 km up to the river, at high tide.

This basin is also prone to flood events. Records show that low-lying next to the River, upstream of Salamanga is susceptible to flooding. With regard to water quality, the River is suitable for irrigation even during the dry season. However, the River is noted for its high suspended solids loads, perhaps indicating erosion upstream.

4.11 Thukela

The environmental issues of concern relate to the environmental flow requirements, the prawn catch-flow relationship and the fish catch-flow link. The Thukela Bank in Kwazulu provides the only significant habitat in the country for commercially valuable group of three species of prawns. These are distinguished by their life cycles, which because of their general occurrence in shallow marine waters and the dependence of the juvenile phase of the estuarine habitats bring them into situations where they are exposed to catchment driven environmental variables. The river discharge has a profound effect on physical, chemical and biological processes in coastal waters. The rivers and estuaries provide a habitat and nursery area as well as providing nutrient and /or detritus to the bank. In terms of the nursery function the river estuaries provide a crucial habitat for the post larva and juvenile stage of the prawn life cycle. Lake St Lucai (Mkuze, Mezene, Hluhluwe and Nyalazi Rivers) and the Mhlathuze River act as nursery grounds. It is important to note that all rivers make a contribution to the nutrient and organic input that is available on the Thukela Bank.

The rivers flows influence marine fish and fisheries directly and indirectly through the export of nutrients, sediment and detritus. Freshwater flows provide cues for migration of estuarine-dependent juvenile and adult fish into and out of the estuarine environment, which dictate the number of individual species move to marine fisheries. A total of 140 species, 60 of which are regarded as important are caught in the Kwazulu Natal line fishery. An estimated 1,200 tonnes are landed yearly. The flow from the Thukela River has a major impact on the catch of the squaretail knob with a reduction of 28% under the worst case scenario.

4.12 Betsiboka

A Global International Water Assessment of the Indian Ocean Islands made an assessment of freshwater shortage, pollution, habitat and community modification, overexploitation of fish and other living resources and global change (UNEP 2004). Several large dams constructed on the main rivers have affected the productivity of the floodplains and the proper function of many lakes. The lakes and rivers are threatened by the generation of high levels of suspended solids due to deforestation, intensive agriculture, particularly from high fertiliser and pesticide use. The impacts on groundwater system are more severe than modification of stream. Human-induced pollution due to improper disposal of solid wastes and eutrophication because of poor treatment facilities is a problem. In addition there is also the risk of oil spills as well as costal erosion and coral bleaching. Solid wastes generated on land end up in the coastal and ocean environment thereby causing degradation of ecosystems and economic impacts.

The fact that 1.8% of the population has access to some form of sewage treatment and over 50% rely on natural disposal systems explains the seriousness of the problem (see below). This is compounded by the fact that 6% of the solid waste is collected routinely while 52% is thrown everywhere. Eutrophication due to improper wastewater treatment, over-application of fertilisers, intensive animal husbandry and industrialisation is another problem. As a consequence there are high concentrations of harmful algae blooms along coast.

Chemical pollution due to mining, port activities, effluent from refinery and pollution in the coastal waters is a big challenge. Coral reefs face medium risk (28%) from threats due to high sedimentation levels from rivers, pollution from agriculture and industries, sewage and solid waste discharges along the coast, pollution from commercial port operations, use of poison in fisheries, coral extraction and collection by tourists. Collapse of the reef system will have significant economic impacts – reef fisheries contribute about 43% of the country's total fish catch and are an important source of food and money.

Overexploitation of mangroves poses problems. It is estimated that a loss of US$600 per ha is incurred every year. Due to poor quality water, poor hygiene levels and sewage contamination there are disease outbreaks with significant infection levels such as malaria (25.8%), diarrhoea (8.5%) and acute respiratory infections (23.3%). Diarrhoea among children is high (up to 25%) especially in the rainy season.

4.13 Summary

Environmental threats are a reality in the region and are a result of a combination of natural and human activities. One of the key areas of concern for the WIO region is the zone of interaction between river basins and the coastal and marine environment where the alteration and/or modifications of freshwater flows, of sediment loads, water quality and pollution are main aspects. Socio-economic activities ranging from agriculture, industry, tourism, provision of social services (water and sewage) do have impact on the environment mostly of a negative character. Based on the descriptions given in this section it may be concluded that all of the twelve rivers covered in this review have been modified by human activities to some degree. In certain cases, the modification is significant, such as Pangani Zambezi and Incomati, as highlighted above. In others, the degree of impact is relatively low – such as the Ruvuma and the Rufiji. Again, when discussing the degree of modification for this transboundary impact study, it is the situation at the outflow of the river which is of interest and direct relevance to transboundary issues. The specific influences of these activities d depend on the importance of each in the various countries.

The specific environmental impacts are many and varied. An observed but less studied phenomenon is reduced stream flows due to upstream water abstractions, sedimentation (due to catchment degradation) and impoundments. The need to address the issue has been highlighted in recent years by the concept of environmental flow requirements. It is fair to say that while widely accepted there are challenges relating to human, institutional and financial capacity to put this on the operational map. In South Africa challenges remain in terms of scope and practicability in various circumstances. Examination of Table 4.9 shows the same trends as highlighted for the Zambezi are repeated where the basins can be placed within the same categories.

Based on the above descriptions it may be concluded that all of the twelve rivers covered in this review have been modified by human activities to varying degrees. The degrees of impacts resulting from land and water use activities in the basins concerned are difficult to quantify and compare. This is due to the fact that no empirical studies using standardised methodologies have been carried out on all the rivers. As the economies of the region develop and populations grow, so will the pressures on the freshwater ecosystems increase, with a commensurate decrease in the quantity, quality and timing of flows into the coastal marine ecosystem.

Table 4.9 Overview of environmental threats across the river basins

Basin	Major environmental threats								
	Stream flow modification	Sediment	Industrial pollution	Agricultural pollution	Mining	Deforestation Settlements	Settlements	Air pollution	Coal-based power generation
Athi-Sabaki	NS	S	NS	S	NS	S	NS	NS	NS
Tana	S	S	NS	S	NS	S	S	NS	NS
Rufjii	NS	NS	NS	S	NS	NS	NS	NS	NS
Pangani	NS	S	S	S	NS	NS	NS	NS	NS
Rovuma	NS	S	S	S	NS	NS	NS	Ns	NS
Zambezi	S	S	S	S	S	S	S	S	S
Maputo	S	NS	NS	S	NS	NS	S	S	NS
Incomati	S	NS	NS	NS	S	S	S	S	S
Limpopo	S	S	S	S	S	S	S	S	S
Thukela	S	NS	S	NS	S	NS	NS	S	NS
Pungwe	S	NS	NS	NS	NS	Ns	NS	NS	NS
Betsiboka	S	S	NS	NS	NS	NS	S	NS	Ns

Source: Adapted from Ashton et al. 2001, Deconsult 1998, AUF n.d.ab Wikipedia 2007ab, Chenje and Johnson 1996, Van der Zaag 2000, World Bank 2004ab

S significant

NS Not significant/negligible

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

One of the key areas of concern for the WIO region is the interface between river basins and the coastal and marine environment where fresh and marine waters mix. Here the alteration of natural freshwater flows, sediment loads and water quality and pollution inputs are the main concerns. Around much of the region many coastal issues are linked to human activities and climatic variability, sometimes with origins that are inland and far removed from the coast. These inland environmental pressures have altered drainage along entire river courses and systems, large and small, thereby impeding the flow and quantity of freshwater, terrigenous sediments and organic matter.

It may further be concluded that all of the twelve rivers covered in this review have been modified by human activities to varying degrees. In certain cases, the modification is significant, such as in the Pangani, Zambezi and Incomati. In few others, the degree of impact is relatively low – such as the Ruvuma and the Rufiji. The majority of the main rivers of the WIO region are thus either moderately or little affected, with five of the rivers classified as severely modified, with measurable impacts on the marine ecology directly associated with them. The latter may therefore be considered as the main 'hotspots' in the region when considering issues related to river-coast interaction. It should be noted, however, that rivers classified as "moderately affected" may have issues which either currently, or in the future pose an environmental threat. This situation, whereby most WIO large rivers are little or moderately affected could change if economic and social development pressures in the basins increase. As the economies of the region develop and populations grow, so will pressures on the freshwater ecosystems increase, with a commensurate decrease in the quantity, quality and timing of flows into the coastal marine ecosystem.

For most of the rivers in the region, pollution of the marine environment from freshwater flows is not significant; although various studies undertaken in the Pangani, Limpopo, Incomati and the Maputo rivers show that there has been some reduction in water quality, but that the spatial-temporal distribution of such reduction is usually insignificant. In a few hotspot areas however, where there are changes to the estuarine environment due to increased pollution levels, reduced flows and changed sediment deposition patterns have severely affected fish and shrimp catches (for example, at the Zambezi Delta), confirming that the estuaries' functions as fish and prawn spawning areas, nurseries and feeding habitats are compromised.

Governance is specifically related to flow alterations from the damming of rivers through dam operating rules. Hydro-power and water supply dams aim to provide maximum hydraulic pressure at times when power is needed most and store wet season runoff for use in the dry season respectively. The net impact is a reduction in the natural flow variability of the river, leading to loss of biodiversity and habitat destruction. For instance, the construction of the Cahora Bassa Dam and its operation and its impact on the downstream fisheries has been mentioned above.

Despite international conventions, national agreements, international and nation responsible institutions, degradation of the coastal and marine environment seemingly continues apace. A key conclusion that may be derived is therefore that cross-cutting governance instruments need to be promoted and developed to meet the unique challenges in the coastal zone. Such instruments and initiatives include ICAM, EIA and SEA. A positive development is recognised whereby virtually all WIO countries have to a greater or lesser degree commenced, or at least considered, the notion of ICZM in their respective jurisdictions, many with EIA policies and legislation in place and operational.

5.2 Recommendations

It is generally realised that the protection, management and development of the shared ecosystems of the WIO region would require a regional approach, because the impacts of the above-mentioned disturbance sources and activities are not confined to national borders. The mobile components of the WIO, such as winds, ocean and tidal currents, and some transboundary rivers, exist on scales larger than geopolitical entities, and over-exploitation, habitat destruction or degeneration in water quality in one part of the WIO consequently adversely impact on one or more neighbouring countries. The underlying cross-cutting theme which emerges from the governance analysis is the need for coordination of the key instruments which together will lead to better governance in the strategy to improve the quality of the coastal and marine waters in the WIO region. At the various levels of governance such instruments would include international, regional and national levels.

The transboundary nature of water resources renders national or local responses, often in isolation, ineffective at addressing the described environmental problems. These can only be solved if they are addressed throughout entire basins, some requiring harmonisation of legal instruments on a regional level beyond the basin scale. Increased cooperation between sectors is also needed to overcome management interventions that are mainly sectoral in nature with little coordination between sectors. It is suggested that these challenges can be addressed by developing appropriate legislative, policy and institutional frameworks to institutionalize public awareness and education programmes. These interventions should involve actions geared at capacity building and education, as well as providing platforms for information exchange and interaction with stakeholders.

One of the biggest challenges faced by countries within the region is obtaining reliable data. Records which do exist tend to be incomplete due to failure of measuring stations and reporting procedures for a variety of reasons. Additionally, the quality of the data is questionable, being measured by different types of instruments, often mixed and corrupted. Several countries in the region have plans for new large-scale water infrastructure and use thus it becomes increasingly necessary to be able to understand the impact of such developments on downstream users and ecosystems. Without sound data on which to base decisions, it is likely that damage to other users and the ecosystem will continue to increase. It is therefore recommended that actions for intervention should be geared at filling gaps in data and information in order to generate the necessary knowledge for better, more sustainable management.

In summary, the following four action categories are defined for intervention for addressing challenges faced by the WIO region:

- **Monitoring and Assessment** - actions geared at filling gaps in data and information in order to generate the necessary knowledge for better, more sustainable management.
- **Management Tools** - actions geared towards the preparation of management tools such as guidelines and investment plans, as well as actions geared towards demonstrating appropriate approaches.
- **Governance** - actions geared towards the development and implementation of governance frameworks, including policies, laws, regulations and standards, as well in stimulating and supporting governments in mainstreaming marine and coastal management in existing policies and budgets.
- **Information management, capacity building and awareness raising** - actions geared at capacity building and education, as well as providing platforms for information exchange and interaction with stakeholders.

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