International River Basins of
AFRICA

Facing the Facts

Assessing the Vulnerability of Africa's Water Resources to Environmental Change

UNEP
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DEPARTMENT OF FOREIGN AFFAIRS
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Every drop counts
Count every drop

Contents

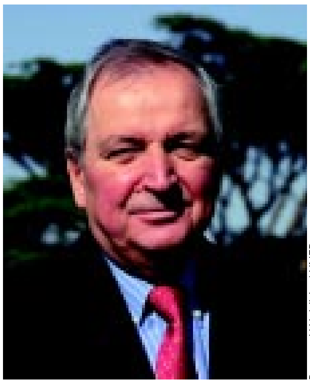
List of Figures, Tables and Boxes

Figures

Tables

Boxes

Foreword



Bernard Wahihia / UNEP

As we proceed with the twenty-first century, one-third of the world's population lives in countries with moderate to high water stress. UNEP was designated as the lead agency of the United Nations for the commemoration of the World Water Day in 2003 during which the first United Nations World Water Development Report was released. The concluding chapter of the report is entitled "The World Water Crisis: Fitting the pieces together". The Report highlighted the water-related threats and vulnerabilities confronting humankind. These vulnerabilities are on the increase.

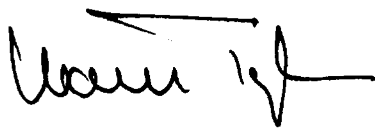
- Development has put additional pressures on water resources and the environment, and those pressures are set to mount further still.
- Freshwater ecosystems continue to be hit hard by reduced and altered flow patterns, deteriorating water quality, infrastructure construction and land conversions. More rivers have been disrupted, fewer rivers retain good ecological status. Biodiversity and fisheries are in a global decline as freshwater ecosystems have been more severely disrupted than land or sea.
- There are also rising costs of water-related disasters, which require practical solutions for mitigating risks and sharing water.

Water is the most vital for human survival; it is also one of the most widely shared resources on the planet. It has the capacity to unite peoples and states that share a source of water, and to incite conflict among them as they compete for it. Throughout the world people are becoming increasingly aware of the degradation of water bodies. Disasters from floods and droughts are now considered to be closely linked with the ongoing global climate change. There is also increasing public concern about the declining quantity and quality of water resources which have culminated in mounting pressure on Governments and decision-makers to institute new and innovative policies to manage water resources in a sustainable manner. The political composition of the world's international river basins, which account for nearly one-half of the earth's land surface, generate 60 percent of global freshwater flows and are home to approximately 40 percent of the world's population, highlights their vulnerabilities.

It is against this background of growing concern about vulnerabilities of water resources to environmental change and human activity that UNEP has significantly strengthened its water assessment and capacity-building activities.

- The GEF-funded and UNEP-implemented Global International Waters Assessment Programme has issued several regional reports on the health of transboundary rivers, lakes, aquifers, and their ecosystems in terms of the environmental, social and economic impacts;
- The Atlas of International Freshwater Agreements, prepared by UNEP in close cooperation with a number of partners, looks at the efforts being made to encourage co-riparian cooperation;
- At the recent 23rd session of the UNEP Governing Council/Global Ministerial Environment Forum, Governments adopted the Bali Strategic Plan for Technology Support and Capacity-Building;
- UNEP released, in February of this year, the Guidebook for Policy and Legislative Development on Conservation and Sustainable Use of Freshwater Resources; and
- The UNEP GEMS Water Quality Programme continues to make an invaluable contribution to global monitoring of the state of the planet's water resources.

The water problems and vulnerabilities confronting us on the eve of the 2005 World Summit can be addressed effectively. But, we must have the will to deal with long-term environmental problems as well as the environmental underpinnings of the vulnerability of water resources. In this regard, we are encouraged by the firm support being extended by a number of governments. The Irish and Belgian governments, respectively, have provided funding for our vulnerability assessment of water resources. African intergovernmental bodies, institutions and experts have joined hands with UNEP in addressing the threats to Africa's ecosystems and related vulnerabilities of the continent's water resources. The ongoing efforts involve the African Ministers' Council on Water, New Partnership for Africa's Development and others. These regional commitments and the international solidarity with Africa have begun to yield tangible results.



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Executive Summary

Africa's high dependence upon natural resources makes its people particularly vulnerable to environmental change. This vulnerability relates to many natural and human phenomena, including climate change and variability, pollution, population growth, competition for water, poor data availability and quality, and knowledge gaps. Vulnerability assessments of water resources are urgently needed in Africa to alleviate the high risks faced by the continent's ecosystems, and to inform and strengthen the coping strategies of poor communities who are less capable of adapting to environmental change.

Acknowledging the urgency of the vulnerability issues affecting Africa's fragile environment and its human livelihoods, UNEP-DEWA and START initiated a study in February 2003 to assess the 'Vulnerability of Water Resources to Environmental Change in Africa'. The aim of the study was to facilitate the management of vulnerability risks at transboundary, national, and local river/lake/groundwater basin levels by assessing the impacts of environmental and human-driven changes on water resources. The results of this study should be of great interest to governments and policy- and decision-makers at various levels, as well as to the affected communities themselves.

In this publication, four regional groups of researchers address the vulnerability issue for their respective regions (Southern, Eastern, Western and Northern Africa) through assessments of selected river/lake/groundwater basins according to natural (physiographic), anthropogenic (socio-economic), and management criteria. Such an effort has never previously been undertaken for the African continent as a whole.

The basin was chosen as the primary unit for assessment for a number of reasons. First, it includes all the main components of the hydrological cycle. Second, it incorporates Integrated Water Resources Management (IWRM) principles, such as equity of access and efficiency of water use in economic and environmental terms. The basin approach also seeks to maintain a balance between competing pressures to ensure long-term resource integrity, social progress and economic growth, and the integrated and sustainable use of environmental resources.

The level of detail of the vulnerability assessments was determined by the study objectives and resource availability. A rapid approach was adopted to provide a summarised overview, including an inventory of important data and information sources. Key issues of vulnerability of water resources to environmental change and adaptation and mitigation options emanated from the rapid assessments. They are summarised in the following diagrams and illustrated by regional and basin examples.

The assessments clearly show that Africa's water resources are already facing a serious risk – and one that will continue to grow over the coming years. The results of this study should thus be regarded as a vital starting point for comprehensive vulnerability assessments of Africa's individual river/lake/groundwater basins, to inform the management of vulnerability risks at various levels.

Key Issues

Physiography	Climate Change & Variability	• Increased frequency of droughts and floods • Small change in rainfall ➤ Large change in river flow …Persistent drought in the Sahel since 1970s… (includes largest part of Niger River Basin)
	Ecosystems	• Biodiversity • Desertification • Wetland degradation …Deteriorating ecosystem integrity of Lake Victoria Basin…
	Surface Water Groundwater	• Limited resources, unevenly distributed and over-exploited …The Nubian Sandstone Aquifer System is a non-renewable water resource… • Pollution …Industrial and municipal effluent loading in Orange River Basin…
Socio-Economy	Demography	• High population growth rate in urban areas • Water-related diseases and HIV/Aids …Southern Africa has the highest incidence of HIV/AIDS … • Poor water and sanitation coverage and service delivery …Inadequate access to clean water and sanitation in peri-urban and rural areas…
	Economy	• Agriculture is the most important economic activity and the biggest water consumer (~80%) • Competition for water …High competition between irrigation and hydropower in the Rufiji Basin…
Management	Legislation Institutional	• Water legislation • Inadequate institutional strength and capacity …Establishment of cooperative frameworks for managing shared waters in the context of IWRM…
	Knowledge	• Data access, sharing, reliability and standardisation • Monitoring • Gaps - Insufficient insight into climate change and variability - Water pollution inadequately addressed - Groundwater recharge largely unknown - Environmental flow requirements largely unknown

Adaptation and Mitigation Options

Institutional & Legislative Framework	• Water sector reforms • Managing (shared) waters and ecosystems • Communities' responses to water stress
Capacity Building	• Capacity enhancement programmes
Data & Monitoring	• Data rescue • Standardised assessments • Monitoring for early warning systems and management
Technologies	• Surface / groundwater storage and use • Rainwater harvesting • Improvements in urban water supplies • Investments in wastewater treatment • Improvements in agricultural techniques • Water trade

1.

Introduction

1.1 Background

The availability of and access to fresh water strongly influence patterns of economic growth and social development (Allan, 2002). In this regard, Africa faces considerable challenges in meeting the social and economic needs of its populations (Hirji et al, 2002). It has become increasingly important that water resource development takes place within the context of Integrated Water Resource Management (IWRM), with its key principles of equitable access, efficiency and sustainability. Africa's high economic dependence upon local natural resources makes the continent particularly vulnerable to changes in the availability of water as a result of environmental changes.

1.2 Vulnerability of Water Resources to Environmental Change in Africa

In February 2003, the UNEP Project, 'Assessing the Vulnerability of Water Resources to Environmental Change in Africa,' was launched to address the vulnerability issue in a broad sense – in terms of physiographic, socio-economic and management-related changes. This report presents contributions from the four African regions (Southern, Eastern, Western and Northern) to this project.

The assessments focus on river, lake and groundwater basins and were carried out in the context of the 2002 World Summit on Sustainable Development, at which the international community made a renewed commitment to the principles of sustainable development outlined in the 1992 Rio Declaration and to the advancement of the United Nations' Millennium Development Goals. Within this context, it is internationally recognised that sustainable development in Africa can only be achieved by simultaneously addressing peace, security and development concerns, including environmental issues, human rights and governance. This overlaps with efforts to formulate a concerted programme of action for Africa's development through the NEPAD initiative (www.nepad.org).

1.3 Report Structure

Chapter 2 of this report provides a framework for the vulnerability assessment. It includes definitions of vulnerability, the motivation for a basin perspective in assessing vulnerability, the identification of parameters and vulnerability indicators, and a three-tiered approach to the assessment process.

Chapter 3 presents vulnerability assessments of water resources to environmental change in the four African regions, as well as more detailed assessments (using the 'rapid' approach) of selected river/lake/groundwater basins. The assessments concentrate on various aspects of vulnerability from physiographic, socio-economic and management points of view.

Chapter 4 provides a synthesis of the key issues related to the vulnerability of water resources to environmental change, together with recommended mitigation and adaptation options.

Chapter 5 presents an overview of references and data sources, including useful website addresses.

2

A Framework for Assessing vulnerability

2.1 Definitions

The degree to which a system is susceptible to, or unable to cope with, adverse effects of environmental change defines its **vulnerability**. With regard to climate change, the vulnerability of a natural, socio-economic system is determined by the character, magnitude and rate of climatic variation on one side, and the sensitivity and adaptive capacity of the system on the other (IPCC, 2001). Spatial and temporal changes in precipitation are of particular concern and relevance to discussions on the vulnerability of freshwater systems.

In many African countries, water demand outstrips available freshwater resources. Countries or regions where such conditions limit development are said to experience **water stress**. Water stress may cause the deterioration of freshwater resources in terms of quantity (overexploitation, environmental degradation, etc.) and quality (eutrophication, pollution, saline intrusion, etc.). Withdrawals that exceed 20% of renewable water supply have been used as an indicator of water stress (IPCC, 2001). Annual renewable freshwater availability of less than 1,000 m^3 per person is defined by hydrologists as **water scarcity**. Such vulnerability issues call for well informed, carefully planned and closely coordinated water resource legislation and management.

2.2 The Basin Perspective

The increasing incidence of water stress has brought about the adoption of new approaches to managing water resources in an holistic and integrated manner. The Rio+10 and Dublin conferences have led to a fundamental paradigm shift from water resource management based on administrative boundaries to management based on hydrological boundaries.

For this study, the river/lake/groundwater basin was chosen as the primary unit for assessment. The basin represents a hydrologic unit that comprises both surface water and groundwater and thus takes into account different components of the hydrological cycle. It incorporates watersheds or catchments, which are defined as "topographically delineated areas drained by stream systems – that is the total land area above some point on a stream or river that drains past that point."

The basin perspective helps to achieve a balance between the interdependent roles of resource protection and resource utilization (Ashton, 2000). It incorporates the principles of sustainability, development, participation and integrated water management, and seeks to promote desirable collective goals such as equity, stakeholder engagement, self-reliance and a healthy environment (Turton and Henwood, 2002). In effect, the basin perspective seeks to maintain a balance between the competing pressures exerted by the need to maintain long-term resource integrity, the compelling call for social advancement, and the desire for continuous economic growth and sustainable use of environmental resources.

The basin perspective represents a progression from supply-oriented water resource development to water demand management (Turton and Henwood, 2002). This progression develops where water demand continues to outstrip supply, even when all available water sources have been developed or are prohibitively expensive to develop, resulting in competition between water uses and users. At this point, water scarcity reaches such a level that the exploitation limits become evident and finding the best possible use of water becomes imperative (Turton and Ohlsson, 2000).

2.3 Parameters and Indicators

For the purposes of this study, parameters and related indicators for assessing the vulnerability of water resources to environmental change were grouped into physiographic (natural), socio-economic (anthropogenic), and management clusters (see Table 2.1). They are linked to sub-clusters and should be applied to various temporal and spatial scales. Please note that the table is not exhaustive, but aims to provide an overview of those parameters and indicators for which data and information are relatively easily available and accessible. Chapter 3 discusses the parameters and indicators for the four regions in more detail.

Table 2.1: Parameters and vulnerability indicators

Cluster		Parameter*	Vulnerability Indicator*	
Physiography	**Climate**	• Rainfall • Evapotranspiration	• Aridity	**Water Scarcity**
	Ecosystems	• Water dependency • Land use • Landcover	• Water availability • Desertification • Storage and supply infrastructure	
	Hydrology	• Stream flow • Storage • Quality		
	Hydrogeology	• Yield • Recharge		
Socio- Economy	**Demography**	• Population size and distribution • HIV/AIDS, water-related diseases • Water demand • Water supply • Value of water	• Population density and growth • Poverty • Access to water • Water use • Conflicts	
	Economy			
Management	**Legislation**	• Policies • Acts • Regulations • Guidelines	• Sector reform • Implementation and adaptive capacity	
	Institutional	• Adherence to IWRM principles • Human resources		
	Knowledge	• Literature/reports	• Data availability, gaps and quality	

*Temporal and spatial variability and trends

2.4 The Three-Tiered Assessment Approach

The level of detail of a vulnerability assessment is determined by the study objective and the availability of resources (human resources, finances, data and information, etc.). For the sake of harmonising future assessments, the following basic three-tiered approach is proposed:

- Rapid: summarised overview, including inventory of sources of data and information;
- Intermediate: a more detailed overview; and
- Comprehensive: in-depth analysis, likely at a smaller spatial scale (pilot areas).

It is our experience that it takes about one month for one person to carry out a rapid vulnerability assessment of one large river/lake/groundwater basin. The subsequent intermediate assessment may take about six months, depending upon the study objectives, whereas a comprehensive assessment may take one year or more.

A **rapid assessment** is carried out according to the following procedure:

Stage 1: Define the spatial scale of assessment using biophysical and socio-economic boundaries;
Stage 2: Define the temporal scale, incorporating current and potential environmental changes;
Stage 3: Collect data and information on the relevant biophysical characteristics of the study area;
Stage 4: Collect data and information on the socio-economic and management characteristics of the area;
Stage 5: Provide a summarised overview.

Having been collected nationally, country-by-country, information in Africa is generally compiled and available according to administrative rather than hydrological boundaries. Information therefore needs to be synthesised. Geographical Information Systems (GIS) offer an opportunity to capture and compile information at the basin scale.

3

Vulnerability Assessments

In this chapter, the vulnerability of water resources to environmental change in Africa is assessed for the Southern, Eastern, Western and Northern African regions, based upon the rapid approach outlined in the previous chapter (Figure 3.1). In each region, two assessments are also carried out on a river/lake/groundwater basin scale: on the Zambezi River Basin and Orange River Basin in Southern Africa; the Victoria Lake Basin and Rufiji River Basin in Eastern Africa; the Senegal River Basin and Niger River Basin in Western Africa; and the Nile River Basin and Nubian Sandstone Aquifer System in Northern Africa. Vulnerabilities are evaluated according to the main physiographic, socio-economic and management-level clusters.

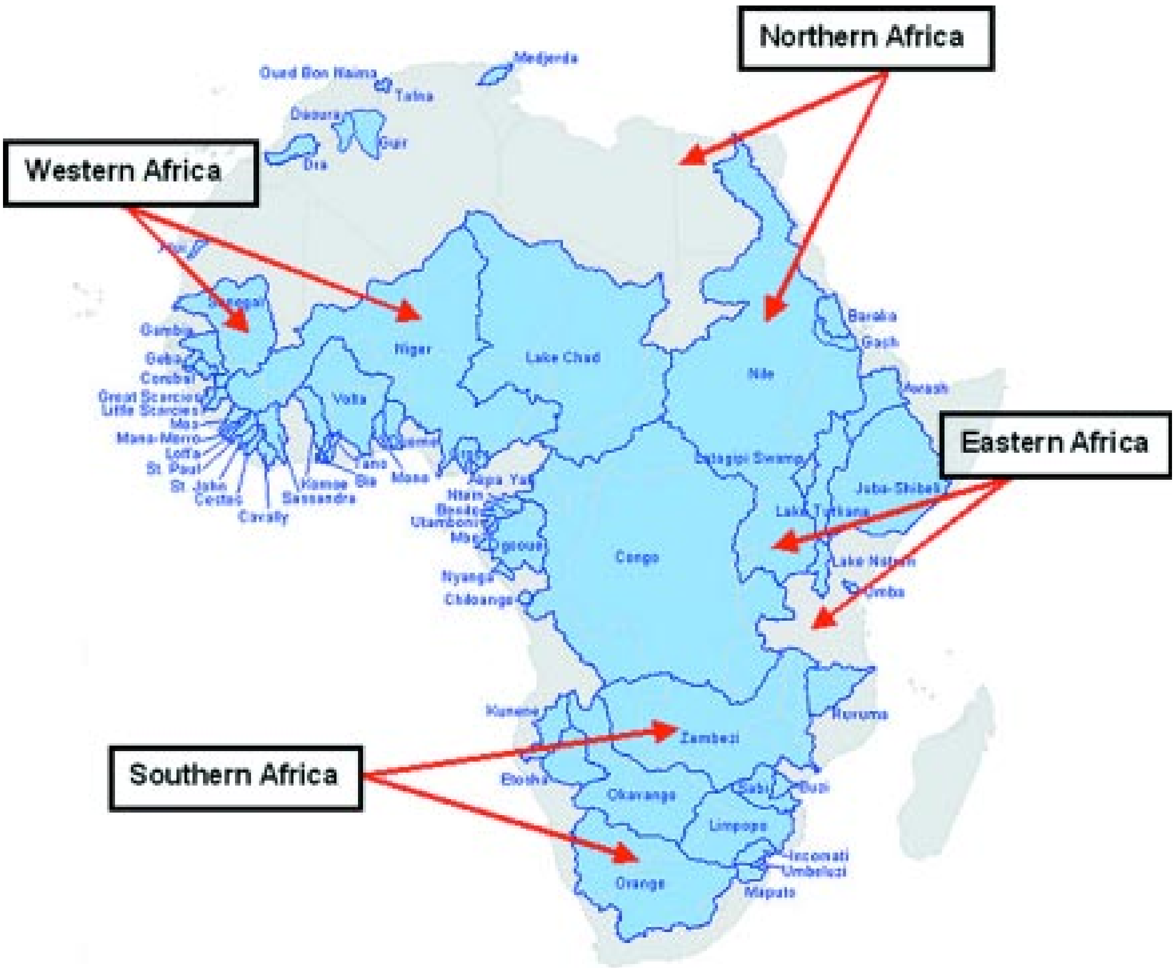

Figure 3.1: International river/lake basins of Africa

(Transboundary Freshwater Dispute Database, 2000)

3.1 Southern Africa

The economies of the Southern African countries are heavily dependent upon agriculture (frequently subsistence) and pastoralism, the yields of which are largely determined by climate variability and water availability. In addition, because of their relatively low development status, the economies and social character of these countries are particularly vulnerable to changes in the availability of water over space and time. Such changes may be defined in terms of the total amount of precipitation received, its frequency of recurrence, the persistence of wet- or dry-day combinations, the onset and duration of the rainy seasons (Schulze et al, 2001), or the quality of available freshwater resources. The extent to which water resources, the environment and economies may be impacted upon by changes in water availability vary considerably.

The four largest Southern African river basins south of the Democratic Republic of Congo are, in declining order, the Zambezi River Basin, the Orange River Basin, the Okavango River Basin and the Limpopo River Basin (Figure 3.2).

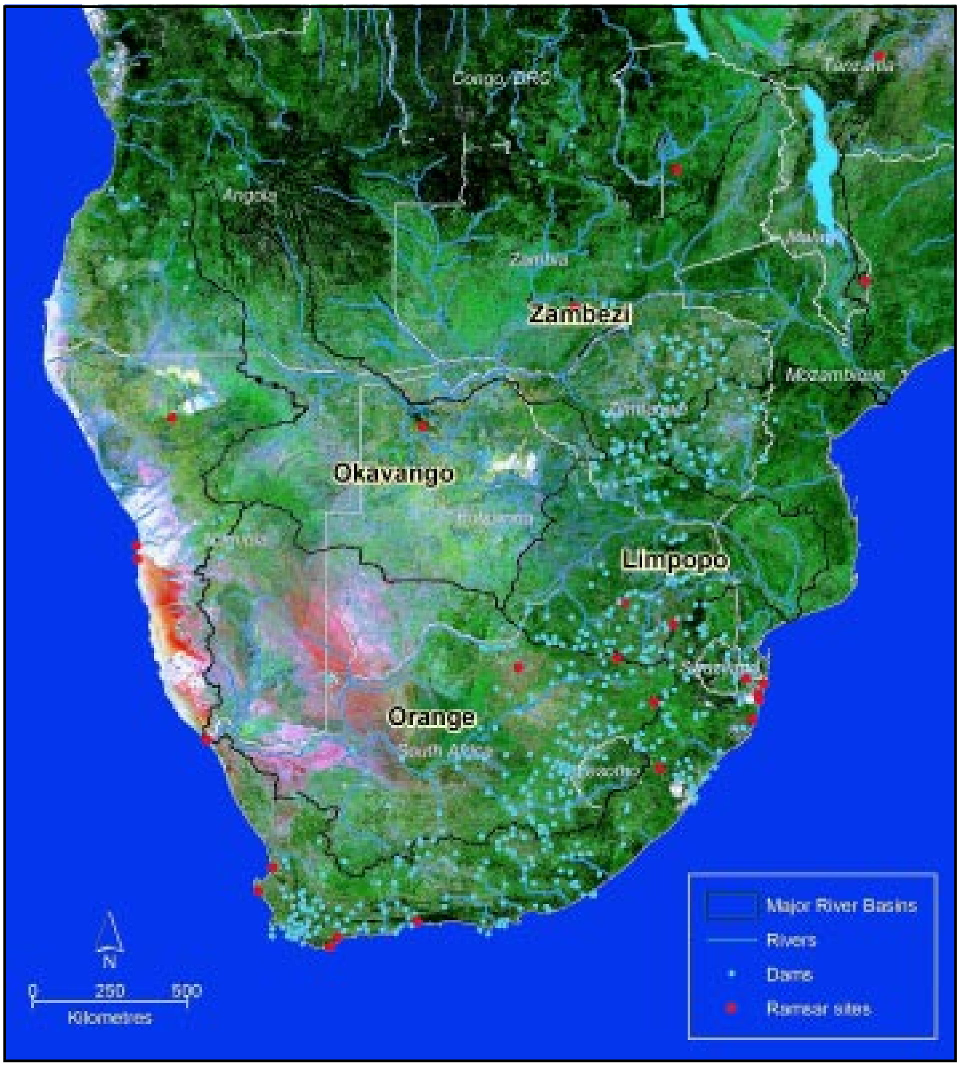

Figure 3.2: Major river basins of Southern Africa

Source: Satellite Image: USGS MODIS, 28 Deccember, 2001
Rivers and Dams: FAO Atlas of Water Resources and Irrigation in Africa – Aquastat, FAO 2001
Ramsar Sites: Ramsar 2003: www.ramsar.org

Physiography

Annual rainfall is highest near the equator and along the east coast, and decreases southward and westward. It ranges from 100 mm in the western parts of Southern Africa to 1,500 mm in the eastern parts. Potential evapotranspiration exceeds the average annual rainfall in most of the region.

Southern Africa has relatively large areas where the natural systems are protected and not significantly impacted by human interventions. Recent developments have seen the joining of protected areas across national borders through the establishment of 'transfrontier parks'. There are 25 wetlands of high ecological importance protected under the 1971 Ramsar Convention (Figure 3.2).

The land cover largely mirrors the climate, with grassland and open shrubland in the west and southwest, savannah in the southeast, and evergreen broadleaf forests in the north. Large areas of cropland are found in eastern and northern South Africa and Zimbabwe (Figure 3.3).

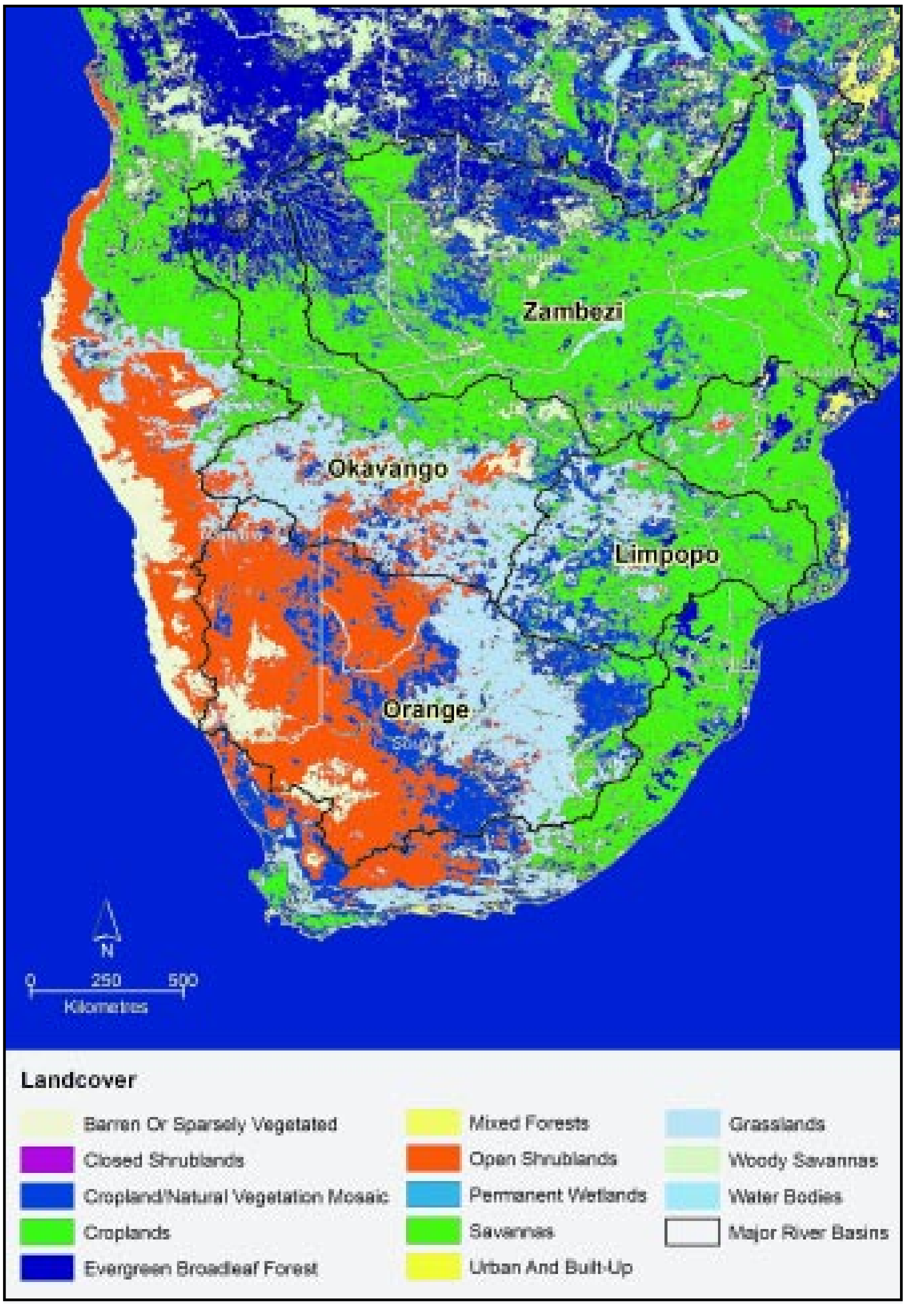

Figure 3.3: Land cover in Southern Africa (IGBP legend)

Source: USGS Africa Landcover Charactersitics Data Base: http://edcdaac.usgs.gov/glcc/glcc.html

The region's renewable freshwater supply is estimated at 650 billion cubic meters, distributed over rivers, lakes and groundwater (Chenje and Johnson, 1996). The occurrence and availability of freshwater resources are unevenly distributed across the region. In some parts, surface runoff is available in sufficient quantities throughout the year, while in others it only occurs with extreme episodic rainfall. Under such conditions people rely largely on dams and groundwater resources.

The renewable portion of groundwater resources (recharge) for the region typically ranges between 1% and 15% of the average annual rainfall (Beekman and Xu, 2003). Particularly in rural areas, groundwater is the main water source for agriculture and domestic supply. It occurs in the following hydrolithological domains: volcanic rocks (e.g. basalt), basement rocks (Precambrian crystalline basement), and consolidated (e.g. sandstone and dolomite) and unconsolidated (e.g. sand) sediments (Figure 3.4). Although the hydrolithological domains do not follow river basin boundaries, aquifers generally do fall within these boundaries.

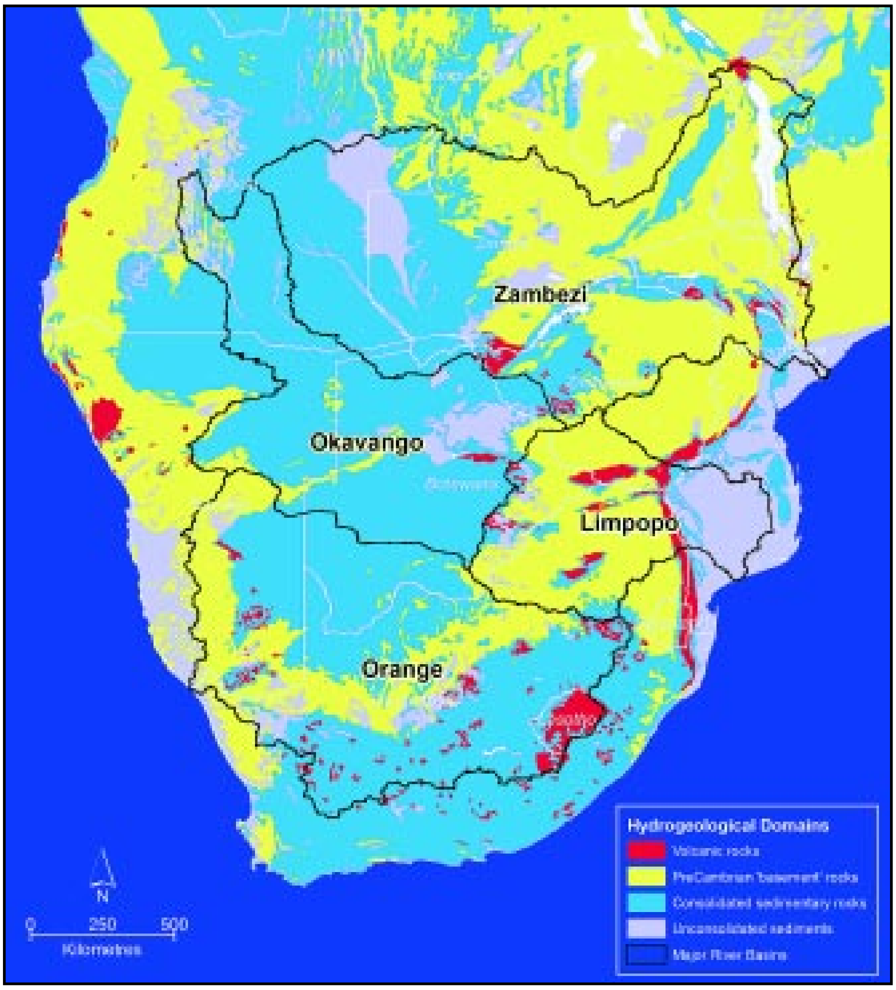

Figure 3.4: Hydrolithological domains of Southern Africa

Source: Adapted from USGS World Energy Resources Products, Generalised Geology of Africa:
http://energy.cr.usgs.gov/oilgas/wep/products/geology/africa.htm
After macDonald, A.M. and Davies, J., 2000

Vulnerability Indicators: Aridity and Water Availability

The highest aridity and therefore vulnerability of water resources to environmental change occurs in the western and southern parts of the region, and decreases to the north and east. Projected figures for 2025 (FAO, 1995) suggest that water availability per person will decrease, largely due to increasing demand and a reduction in accessibility resulting from growing urban populations, environmental change, pollution and other factors.
For Malawi and South Africa, in particular, the projections are bleak.

Socio-Economy

The population of Southern Africa (excluding the Democratic Republic of Congo) was estimated to number about 150 million people in 2000. Population growth rates are high: 1.5 to 3%. In all countries, a strong trend exists towards urbanisation. As a result, the population growth rates of towns and cities are much higher than national population growth rates. These high growth rates place further demands on clean water supplies and sanitation.

Broad disparities exist between the levels of development in the countries of Southern Africa. Of the 11 Southern African states, five are among the lowest-ranking countries on the UNDP's Human Development Index. In order to advance their human development, governments have adopted a number of targets, known as the Millennium Development Goals (MDGs) (UN, 2000; UN-WWDR, 2003). The 7th MDG requires that governments adopt sustainable resource management policies and reduce by half the number of people who do not have access to safe water and sanitation by 2015.

The economies of Southern Africa are largely based on natural resources, with mining and agriculture contributing the greatest economic outputs. Agriculture contributes 9% of the region's GDP (1996), but provides 60% of its employment. The impact of social instability and war has constrained growth and development across the region. Angola, Malawi, Mozambique and Zambia have some of the largest foreign debts in the world (Jubilee, 2000).

Southern Africa also suffers from the world's highest regional incidence of HIV/AIDS, with Botswana (35.8%), Swaziland (25.3%), Lesotho (23.6%) and South Africa (22.6%) bearing the brunt of the pandemic (Ashton and Ramasar, 2002). AIDS continues to contribute to falling life expectancies across the region, and has major implications for the water sector in terms of demand and supply, sanitation and service provision.

The pivotal role of women, as guardians of the environment and users and carriers of water, needs to be reflected in all aspects of water resources management.

Vulnerability Indicators: Water Demand and Water Use
Increasing water demand across Southern Africa is driven by high population growth (2-3.5% per year), urbanisation, improved living conditions, and industrial and agricultural development. Increasing water demand and water use result in less water being available.

Vulnerability Indicator: Population Density and Growth
The population growth rates of towns and cities are significantly higher than national population growth rates. The main population centres in Southern Africa are concentrated along the east coast. This strong trend towards urbanisation places further demands on clean water supply and sanitation.

Vulnerability Indicator: Water-Related Conflicts
Present population trends and patterns of water use suggest that more African countries will exceed the limits of their economically usable land-based water resources before 2025 (Ashton, 2002). The largest water-related conflicts may be expected in connection with the Lesotho Highlands Water Project, the Kariba and Cahora Bassa dams, the Limpopo River, and the Eastern Caprivi region.

Management
Southern African countries practice an increasingly integrated approach to their water resources management, with surface water, groundwater, socio-economic and other issues being considered simultaneously.
The establishment of new institutions with new functions, responsibilities, legislation and guidelines for water management and development takes place at a different pace and at different scales in each country. South Africa and Zimbabwe promulgated their new Water Acts in 1998, whereas other countries such as Namibia and Zambia are in the process of revising their old acts.

Water is an increasingly scarce commodity in the region and it is foreseen that, in the next 20 to 30 years, three or four SADC states will be facing serious water shortages. In recognition of the importance of a coordinated approach to the utilisation and preservation of water, SADC member states signed the Protocol on Shared Watercourse Systems at the 1995 Summit in South Africa. The main thrust of the protocol is to ensure the equitable sharing and efficient conservation of shared water resources. The protocol also describes the establishment, objectives, functions, and financial and regulatory frameworks of River Basin Management Institutions.

Vulnerability Indicator: Sector Reform
Since the late 1990s, there has been significant progress in water sector reforms in Southern African countries, which will create an enabling environment to mitigate against the adverse effects of environmental change on water resources.

Vulnerability studies in Southern Africa
As one of the world's most drought-prone regions, most vulnerability studies in Southern Africa have focused on the impacts of droughts and climate change on local water resources. Indications are that climate change may increase the periodic occurrence of drought in the region (Ohlsson, 1995). Recurring droughts continue to pose a serious challenge to food security and result in an increased reliance upon groundwater. Certain studies have focused on groundwater recharge, which is a critical parameter in determining water availability and thus water scarcity. Changes in recharge will result from changes in effective rainfall and in the timing of the rainy

seasons. In general, in a scenario of global warming, increasing temperatures result in decreasing precipitation over the central continental areas, causing decreasing recharge and thus depletion of groundwater resources.

Studies on the vulnerability of water resources to climate change in Southern Africa include:

- Hulme (ed.) (1996): Annual surface water runoff in the SADC region at 0.5° resolution
- Meigh et al. (1998): An assessment of water availability in Eastern and Southern Africa at 0.5° resolution; includes a demand/supply study (for both surface and groundwater)
- Cambula (1999): Impact of climate change on the water resources of Mozambique
- Schulze and Perks (2000): Detailed modelling exercises covering South Africa, Lesotho and Swaziland at 0.25° cell resolution, and applied to 1946 Quaternary catchments
- Cavé et al. (2003): Impact of climate change on groundwater recharge estimation.

3.1.1 Zambezi River Basin

South of the Congo River Basin, the Zambezi is the largest river basin in Southern Africa (Figure 3.5). It has a catchment area of about 1,390,000 km^2. This transboundary river basin includes parts of Angola (18%), Botswana (1%), Malawi (8%), Mozambique (12%), Namibia (1%), Tanzania (2%), Zambia (42%) and Zimbabwe (16%).

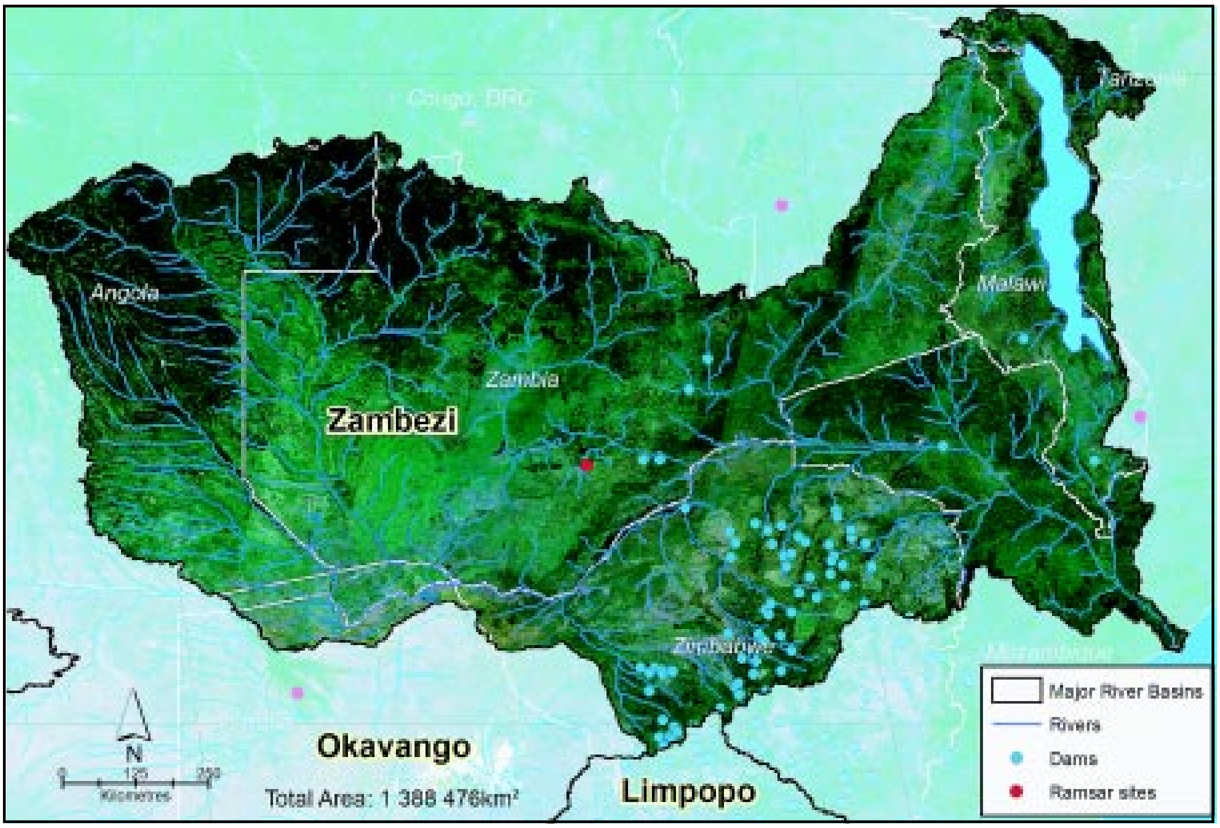

Figure 3.5: Zambezi River Basin

Source: Satellite Image: USGS MODIS, 28 Deccember, 2001
Rivers and Dams: FAO Atlas of Water Resources and Irrigation in Africa – Aquastat, FAO 2001
Ramsar Sites: Ramsar 2003: www.ramsar.org

The Zambezi River originates in the Angolan Highlands and drains into the Indian Ocean. Some of the features of the river basin are floodplains, swamps, lakes and dams. Box 3.1 summarises the basin's main characteristics. More than 30 large dams have been built in the basin with an estimated total capacity of 221,000 million m^3 (Mm^3). Water resources in the basin are still sufficient to meet current human demands, but this situation is expected to deteriorate with continuing population growth. The most significant increase in water consumption is likely to be generated by large-scale irrigation projects.

Physiography

Most rainfall occurs during the summer season between October and April. Rainfall in the basin averages 990 mm per year (Savenije and Van der Zaag, 1998). The northern parts of the basin (Malawi, Tanzania, and northern and western Zambia) receive an average annual rainfall of 1,200 mm, while the southern and southwestern parts receive 700 mm. Average annual actual evapotranspiration is 870 mm, ranging from 1,000 mm in the Luangwa, Shire and lower parts of the basin to 500 mm in the southwestern parts of the basin.

Box 3.1: Zambezi River Basin – Main characteristics

Basin:		**Water Use**
Surface area:	1,388,000 km^2	Agriculture
MAP:	700 – 1,200 mm/a	Domestic
		Industry
		Mining
		Hydropower
Demography		
Population:	25.4 million	
Density:	18 persons/km^2	
Water Resources		**Vulnerability**
River length:	2,650 km	Increasing to the east
MAR:	94,000 Mm^3/a	
Major Dams		
Kariba:	160,000 Mm^3	
Cahora Bassa:	52,000 Mm^3	
Itezhitezi:	5,600 Mm^3	
Total dam storage:	221,245 Mm^3	
Major Aquifers		
Crystalline basement		

Source: Pallett, 1997; Hirji et al, 2002

There is only one Ramsar protected wetland in the Zambezi River Basin: Kafue Flats. National parks and game reserves in the basin include the Kameha Park (Angola), the Chobe National Park (Botswana), the Chobe and Kasane Forest Reserves (Botswana), and the Caprivi Game Reserve (Namibia). A total of 122 fish species are found in the basin, of which seven are alien species (World Resources Institute: http://www.iucn.org/themes/wani/eatlas/index.html). Twenty-five species are listed as endemic, while one is listed as threatened with extinction. Three bird species are endemic.

Savannahs cover almost half of the total land area (Figure 3.3). This is in part a result of the removal of 43% of the basin's original forest cover (Revenga et al, 2000). Population growth and the development of agriculture are expected to result in a continuation of this trend. Evergreen broadleaf forests still cover large parts of the basin (14%), although these are largely restricted to the Angolan and northern Zambian sections. At least 20% of the basin area is under crop cultivation.

The volume of annual renewable water resources in the Zambezi River is estimated at 3,600 m^3/s or 87 mm of equivalent rainfall, which is just under 10% of the basin's average rainfall (Savenije and Van der Zaag, 1998). Plans for further development of the Zambezi River and its tributaries focus mainly on the expansion of agriculture to secure food supplies, the tapping of hydroelectric energy, and the construction of water transfer schemes to supply large urban centres. It is estimated that a further 500,000 hectares of agricultural land could be brought under irrigation by 2030 (Pallett, 1997). No major dam projects are planned in the foreseeable future.

The Zambezi Basin is predominantly underlain by basement rocks (Figure 3.4). Groundwater from these areas is generally of a good chemical quality, although it may be potentially corrosive (Chilton and Foster, 1995). The southern part of the basin is underlain by sedimentary rocks of the Karoo succession, with sandstone layers and dolerite intrusion forming the aquifers. Groundwater abstracted from these rocks tends to be of poorer quality, with higher dissolved solids than the hard-rock (basement) aquifers. The quality usually varies spatially, both over short distances and according to depth. This variability is usually a reflection of locally complex groundwater flow regimes.

Socio-Economy

Population figures from 1994 indicate that there are just over 25 million people living in the Zambezi Basin. This translates into an average population density of 18 people per square kilometre. Ten large urban centres with populations exceeding 100,000 are found in the basin. The present growth rate of urban centres is estimated at 5% (Revenga et al, 2000).

The Zambezi River and its tributaries are vital to the livelihoods of the populations that live in the river basin countries. Over 30 large dams in the basin provide domestic, industrial and mining water supplies, irrigation and power generation. The estimated hydro-electric power potential of the Zambezi Basin is 20,000 MW, of which about 4,500 MW has been installed to date (Pallett, 1997).

The main focus of economic activity in the Zambezi Basin is agriculture and mining. The region is largely underdeveloped, with high unemployment and widespread poverty. The main agricultural products are corn, sorghum and rice, while mining concentrates on copper deposits. Tourism provides a significant part of government revenues. At the same time, the ecosystems of the Zambezi River offer a wide range of natural resources (including fisheries and forestry) that support local communities.

Management

Zimbabwe has only recently (1998) changed its water legislation and institutional framework to adopt an integrated approach to water resource management (GR Zimbabwe, 1998; 2001). In Zambia, legislative and institutional reform is currently underway (GR Zambia, 2003).

In the mid 1980s, riparian states formulated and adopted the Zambezi River Basin Action Plan (ZACPLAN) to establish mechanisms for common management of the river (Shela, 1998). Unfortunately, only a few of the 19 envisaged projects in the plan have since been financed and implemented. One of the projects – the establishment of a Basin Treaty for common management – became redundant with the development of the SADC Protocol on Shared Watercourse Systems in 1995. The establishment of a competent basin institution tasked with the coordination and implementation of the ZACPLAN was not pursued. The failures of water resource management programmes and the slow progress of the ZACPLAN's implementation can most likely be attributed to institutional weaknesses and lack of budget provisions. It is clear that bilateral agreements between the basin states (e.g. between Zambia and Zimbabwe: Zambezi River Authority) and major water-related projects must be adequately integrated into the management strategy and adopted by the basin states.

3.1.2 Orange River Basin

The Orange River Basin is highly developed, with many dams and transfer schemes harnessing and controlling its flow. About 60% of the ~1,000,000 km^2 area of the Orange River Basin lies in South Africa (Figure 3.6), with the remainder in Botswana (13%), Namibia (25%) and Lesotho (2%), which it completely encapsulates.

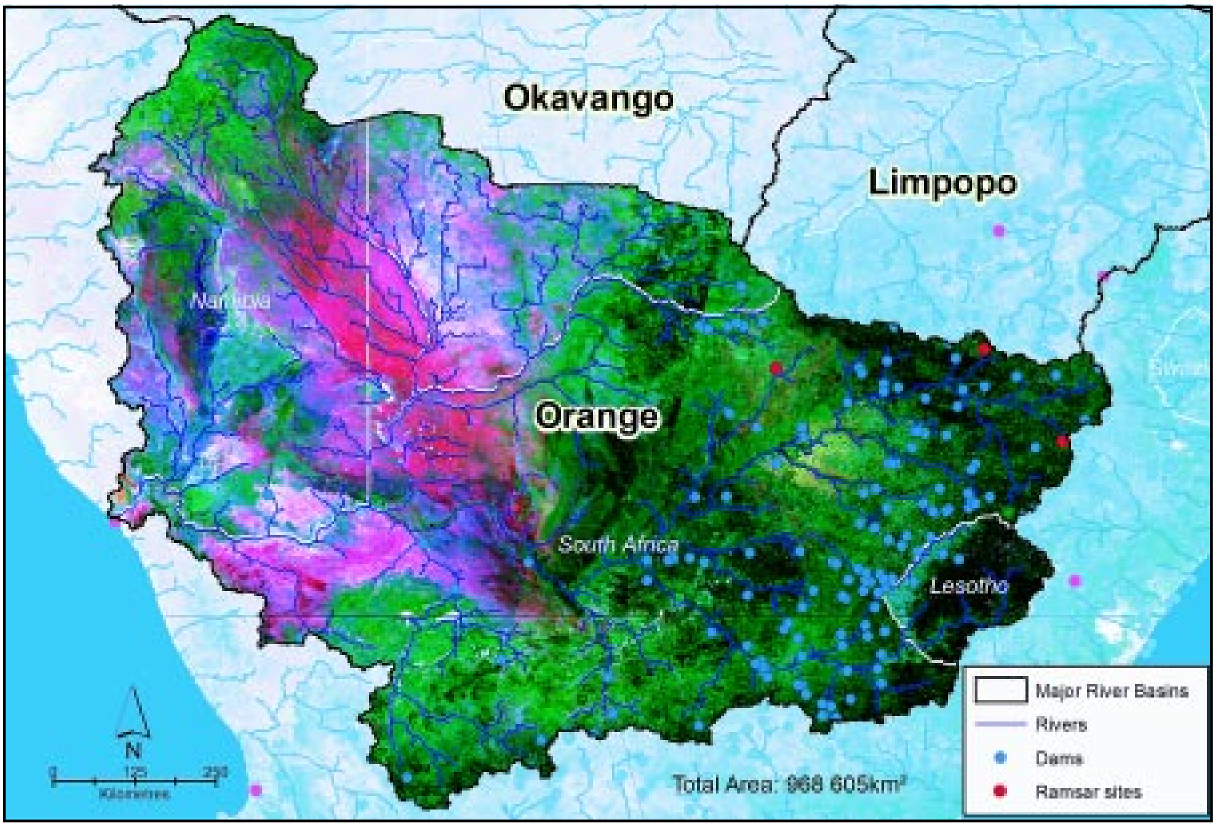

Figure 3.6: Orange River Basin

Source: Satellite Image: USGS MODIS, 28 Deccember, 2001
Rivers and Dams: FAO Atlas of Water Resources and Irrigation in Africa – Aquastat, FAO 2001
Ramsar Sites: Ramsar 2003: www.ramsar.org

Although Botswana and Namibia are part of the Orange River Basin, their role in the watercourse is less significant due to the fact that the nearest point of the Botswana border is 200 km away from the river and very little input is gained from the Fish River in Namibia except during floods. The river originates in the Lesotho Highlands in the east and drains into the Atlantic Ocean in the west. Box 3.2 summarises the main characteristics of the river basin.

Physiography

The mean annual rainfall in the Orange River Basin is about 400 mm per year, with a high degree of variability from approximately 2,000 mm per year in Lesotho to about 50 mm per year at the Orange River mouth. Potential evaporation is equally variable, from 1,200 mm per year in Lesotho to 3,500 mm per year at the river mouth.

Box 3.2: Orange River Basin – Main characteristics

Basin:

Surface area:	1,000,000 km^2
MAP:	50 – 1,500 mm/a

Water Use

Agriculture
Domestic
Industry
Mining
Hydropower

(Increasing ↑)

Demography

Population:	11 million
Density:	12 persons/km^2

Water Resources

River length:	2,300 km
MAR:	11,500 Mm^3/a

Vulnerability

Increasing aridity to the wast

Major Dams

Gariep:	5,675 Mm^3
Vanderkloof:	3,237 Mm^3
Sterkfontein:	2,617 Mm^3
Vaal:	2,122 Mm^3
Katse:	1,950 Mm^3
Total dam storage:	20,412 Mm^3

Major Aquifers

Sedimentary

Source: Pallett, 1997; Hirji et al, 2002; http://www.dwaf.gov.za/orange/

Among the more valued natural resources in the river basin is a transboundary Ramsar protected wetland at the mouth of the Orange River. Important nature conservation areas include the Kgalagadi Transfrontier Park, the Ai-Ais-Richtersveld Transfrontier Park, and the Augrabies Falls Nature Reserve. A review of biodiversity information by Revenga et al (2000) shows that a total of 24 fish species are found in the basin, of which seven are endemic, two of which are threatened with extinction. Two endemic bird species occur in the basin.

The land cover of the Orange River Basin reflects the large variation in precipitation and elevation (Figure 3.3). The largest part of the basin is semi-arid, limiting agricultural activity in most areas to livestock husbandry. Analysis of Landsat imagery shows that grassland and shrubland dominate land cover in the basin.

A wealth of information from the South African part of the Orange River Basin is available on surface water resources, both digitally and in various maps and data volumes at a quarternary catchment scale (Midgley et al, 1994). The data and map series span 70 years of monitoring (1920-1990). Valuable information is also found in Schulze's 1997 *Atlas of Agrohydrology and Climatology.*

Large-scale infrastructural development (dams etc.) in the catchment results in only half of the 11,000 million m^3 annual runoff reaching the Orange River estuary in the west. Runoff extremes have been recorded between 26,000 million m^3/yr and as little as 1,100 m^3/yr due to climatic variations (Conley and Van Niekerk, 1998).
A number of dams and transfer schemes are responsible for moving water in and out of the Orange River, including:

- The Orange River Project, which transfers water from the Caledon and Orange Rivers to the Modder and Riet Rivers of the Eastern Cape;
- Tugela-Vaal Water Project, which transfers water from the Tugela River into the Vaal River to meet high demands in the large industrial and population centres of South Africa's Gauteng Province;
- The Orange-Fish Tunnel Project, which supplements the flow of the Fish and Sundays Rivers of the Eastern Cape (Pallett, 1997); and

- The Lesotho Highland Water Scheme, which transfers water from the headwaters of the Orange River to the Vaal River (http://www.sametsi.com/).

The surface water resources of the Orange River Basin are largely exploited to their optimum. The completion of the Mohale Dam in Lesotho will probably signal the end of large-scale water resource developments in the basin. Although the large number of dams and transfer schemes in the Orange River Basin serves to mitigate the occurrence of flood and drought events, it seems likely that climate change will result in increased precipitation variability and thus increase the frequency of floods and droughts.

The geology of the Orange River Basin is dominated by the consolidated sedimentary rocks of the Karoo succession, the volcanic extrusives of the Lesotho Highlands, dolomite successions and Kalahari sand cover (Figure 3.4). Of these, only the Kalahari sands contain water in primary openings. Groundwater is contained mainly in fractures and larger dissolution openings. For the South African part of the Orange River Basin, detailed hydrogeological information can be obtained from Vegter (1995; 2001).

Groundwater exploration in the Orange River Basin is presently focussed on the location and development of:

- Zones of dolerite intrusions and their hardened contact zones in the Karoo sediments. Yields vary, but are generally less than 4 m^3 per hour. The value of this type of aquifer is that it occurs in the semi-arid interior of the region where few alternative water sources are available;
- Cavities in Karstic dolomite and limestone deposits. At some places these caverns are traversed by veins of dolerites and syenites dividing them into independent water-bearing compartments with considerable stocks of water. Examples of the storage in these compartments are the 730 Mm^3 in the Oberholzer compartment and 450 Mm^3 in the Venterpost compartment; and
- Beds of higher permeability in the Kalahari sand succession. In parts of the Kalahari, groundwater quality is poor, and in some places it may be too saline for use.

Groundwater use in the Orange River Basin largely serves agricultural demands, particularly livestock watering, and water supplies to rural towns and villages. Groundwater recharge is one of the critical parameters in determining water availability and, when related to water use, in determining water scarcity. Figure 3.7 depicts the mean annual recharge in the basin. The map is a compilation of Vegter's provisional recharge map of South Africa (1995) and the recharge map published in the Botswana National Water Master Plan in 1992 (Department of Water Affairs Botswana, 1992; Gabaake, 1997). Despite the great number of recharge studies which have been carried out in Botswana and South Africa (Beekman and Xu, 2003), much more work is needed before reliable maps can be produced depicting spatial and temporal variability in recharge at local and regional scales. Particularly in semi-arid areas, such as in the western parts of the basin, recharge should rather be evaluated in terms of episodic events.

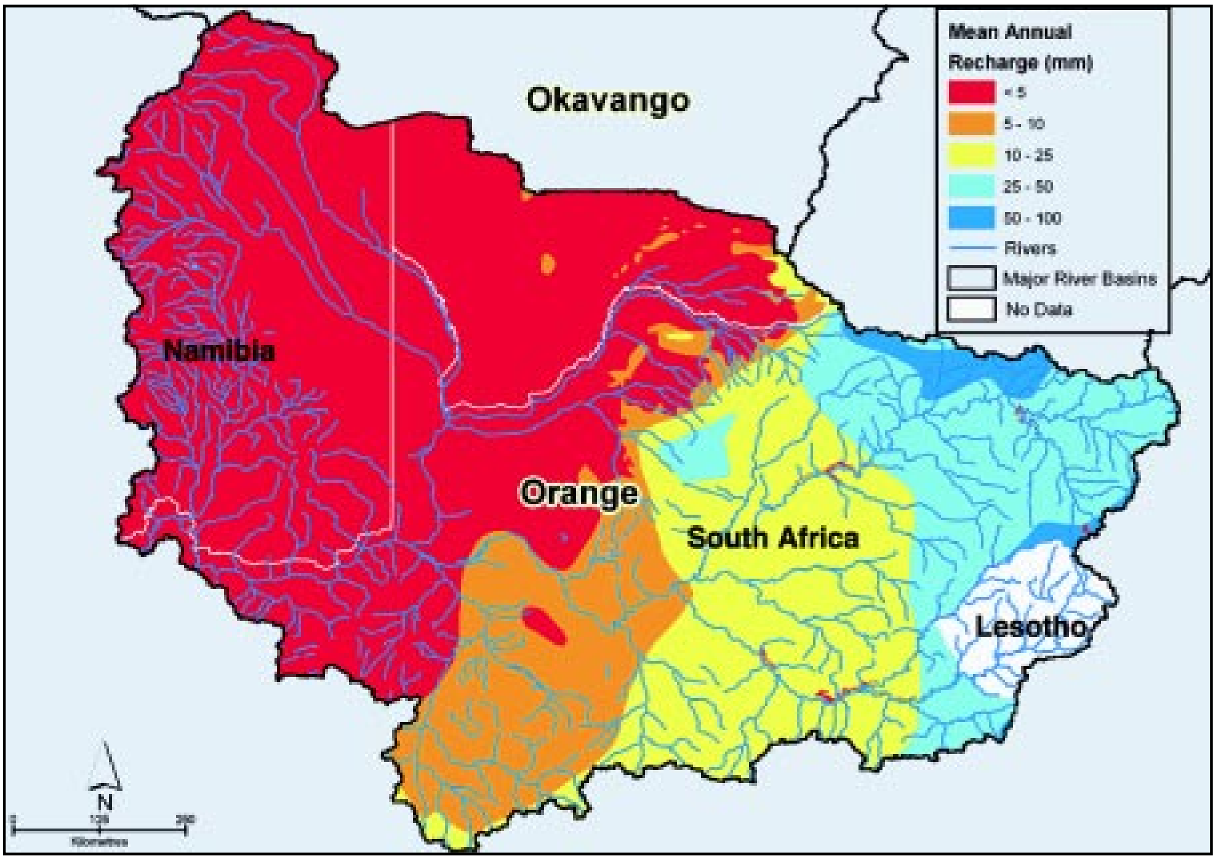

Figure 3.7: Mean annual groundwater recharge in the Orange River Basin

Source: Department of Water Affairs Botswana, 1992, Vegter, 1995
Namibian part of the basin: pers. comm. J. Wrabel, Department of Water Affairs

Socio-Economy
Population distribution in the Orange River Basin is dominated by the large industrial conurbation in South Africa's Gauteng Province, where the lure of apparent opportunity and wealth has resulted in an urban growth rate of 4.6%. By contrast, the northern and western parts of the basin are sparsely populated. The basin as a whole is home to over 11,000,000 people, with an average population density of 12 people per square kilometre.

Economic activity in the basin is dominated by the large-scale industrial, manufacturing and mining sectors in Gauteng. The highly developed economy of this province contributes close to 40% of South Africa's GDP. Much of the dam construction in the basin is geared towards meeting the water demands of Gauteng and has impacted on the structure and functioning of the aquatic ecosystems.

Management
South Africa plays a key role in the management of water resources within the Orange River Basin. South Africa's water resources are governed by the Water Services Act of 1997 and the National Water Act of 1998. These acts are complementary and serve to provide a framework for sustainable water resource management while enabling improved and broadened service delivery. The National Water Act is founded on the principle that all water forms part of a unitary, interdependent water cycle, and that all water should thus be governed in a consistent manner. An IWRM approach that recognises the connection between water, land, human development and the natural environment is now being implemented in most of the Southern African countries.

An agreement was signed in 2000 by the river basin states of Botswana, Lesotho, Namibia and South Africa to establish the Orange Senqu River Commission (ORASECOM), which aims to develop the Orange River for the benefit of all the respective states. ORASECOM is the first formal body established for the management of shared water resources since the Protocol on Shared Watercourse Systems became an instrument of international water law in the Southern African Development Community. The commission plans to develop a comprehensive perspective of the Orange River Basin, study the present and proposed uses of the river system, and determine future requirements for flow monitoring and flood management. It is expected to strengthen regional solidarity and enhance socio-economic cooperation. The multilateral commission will not replace existing bilateral commissions between any of the watercourse states, but rather will provide a broader forum for overall consultation and coordination between the states for sound integrated water resources management and development in the Orange River Basin. Despite this positive new development, however, the central problem of inequitable access to water still remains essentially unsolved.

3.1.3 Comparison of Zambezi and Orange River Basins

Table 3.1 presents a brief summary of the main aspects of water resource vulnerability in the Zambezi and Orange River Basins, according to the physiographic, socio-economic and management clusters.

Table 3.1: Water resource vulnerability in the Zambezi and Orange River Basins

Cluster	Vulnerability Indicator*	Zambezi River Basin	Orange River Basin
Physiography	**Aridity**	<20% of the area	>50%
	Water availability	Vulnerable	Stressed
	Storage and supply infrastructure	Well developed - middle course	Highly developed - upstream
Socio- Economy	**Population density**	18 persons/km^2; downstream increase; variable	12 persons/km^2; upstream increase; variable
	Access to safe water	Urban ~70%, rural ~45%; highly variable	Urban ~70%, rural ~45%; variable
Management	**Water use**	Agriculture ~80%	Agriculture ~60%
	Poverty	Higher	Lower
	Conflicts	Eastern Caprivi region	Lower Orange River
	Sector reform	In progress	Advanced
	Implementation and adaptive capacity	Moderate to bad	Reasonable
	Data availability, gaps and quality	Moderate to bad	Reasonable

Physiography

- Over 50% of the area of the Orange River Basin can be classified as hyper-arid to semi-arid, with aridity increasing to the west. Although the Zambezi River Basin is less arid on an average annual basis, severe droughts, such as the one in the early 1990s, can cause temporary conditions of increased aridity.
- Water availability is particularly critical in the Orange River Basin. Climate change and climate variability are expected to aggravate the situation by decreasing rainfall, runoff and recharge in large parts of both the Orange and Zambezi River Basins.
- The Orange River Basin is highly developed in comparison to the Zambezi River Basin, with many dams and transfer schemes in the upstream regions, although the total storage of its major dams is tenfold less.

Socio-Economy

- Some projections (UN World Population Prospect) predict a doubling of the SADC population by 2050.
- The impact of the HIV/AIDS pandemic on water demand and supply, and water and sanitation service provision, must be analysed in more detail and integrated into water and sanitation policy frameworks.
- The pivotal role of women, as guardians of the environment and users and carriers of water, should be reflected in all aspects of water resources management.
- The combination of population growth (although reduced) and urbanisation puts further pressure on the provision of safe drinking water and sanitation, especially in the urban areas of the river basins. Access to safe water and sanitation is usually much better in urban than in rural areas, but differs strongly between nations (Ashton and Ramasar, 2002). The figures given in Table 3.1 are averaged values and are merely indicative. Differences between nations in terms of access to safe water and sanitation are more pronounced in the Zambezi River Basin.
- The GDP of each of the riparian states of the river basins (except for Lesotho) suggests a healthier economy for the Orange River Basin as a whole than for the Zambezi River Basin. If poverty is expressed in terms of per

capita GDP or the Human Development Index (HDI), it is more prevalent in the Zambezi River Basin than in the Orange River Basin.
- In most Southern African countries, agricultural water use is much higher than domestic and industrial water use: ~80% of the total use in the Zambezi River Basin and ~60% in the Orange River Basin (Ashton and Ramasar, 2002).
- Many of the water-related conflicts already experienced in Southern Africa are likely to continue in the future as a result of escalating demands and pressures on the region's finite and scarce water resources (Ashton, 2000). The degree of international conflicts, however, is expected to be limited. Ashton observed a remarkable correspondence between sites of actual or potential water conflict and the absence or scarcity of perennial rivers or lakes in Africa. Examples of actual and potential conflicts in Southern Africa are the Eastern Caprivi region bordering Botswana, Namibia and Zambia (ownership of islands) and the lower reaches of the Orange River bordering Namibia and South Africa (territorial and water-related rights; Ashton, 2000).

Management
- Water sector reforms are underway in both river basins, with new water-related legislation and guidelines in place or in preparation, and the establishment of new institutions for the management of water resources on the basis of hydrologic boundaries. The Orange River Basin is the most advanced in its reforms and their implementation. On a basin level, an agreement was signed in November 2000 by the four riparian states for the establishment of the Orange-Senqu River Commission.
- Regarding data availability and knowledge gaps, more information of a better quality and greater detail is available for the Orange River Basin for all the physiographic, socio-economic and management clusters than for the Zambezi River Basin. Although the majority of the rural communities in both river basins rely on groundwater for their domestic requirements, information on groundwater resources is less detailed and accurate in comparison with surface water resources.

Water Scarcity
- Water availability in the Orange River Basin is already at a critical stage. When combined with the relatively high water demand and withdrawals for agricultural use, this basin is among the most severely water-scarce regions in Africa. Future projections of the various physiographic, socio-economic and management data suggest a further aggravation of the situation if there are no appropriate human interventions. The same holds true for the Zambezi River Basin, although water availability seems to be less critical at the moment.

3.2 Eastern Africa

More than 70% of the population of Eastern Africa is rural and practices subsistence agriculture (WHO/UNICEF, 2000). Rapid population growth and increasing demand for food, combined with the high variability in rainfall and frequent droughts, are putting growing pressure on natural resources. Analyses of current economic and environmental trends reveal increasing competition over access and use of freshwater resources, at the same time that population growth, industrialisation and climate change are adding stress to these resources. There is also competition for access to water resources between countries, some of which depend on fresh water not only for domestic, agricultural and industrial consumption but also for hydropower generation. Freshwater availability and access are thus priority issues for the entire region.

The major river basins in Eastern Africa that are internationally shared include: Rufiji, Juba, Victoria/Upper Nile, Turkana and Shaballe (Figure 3.8).

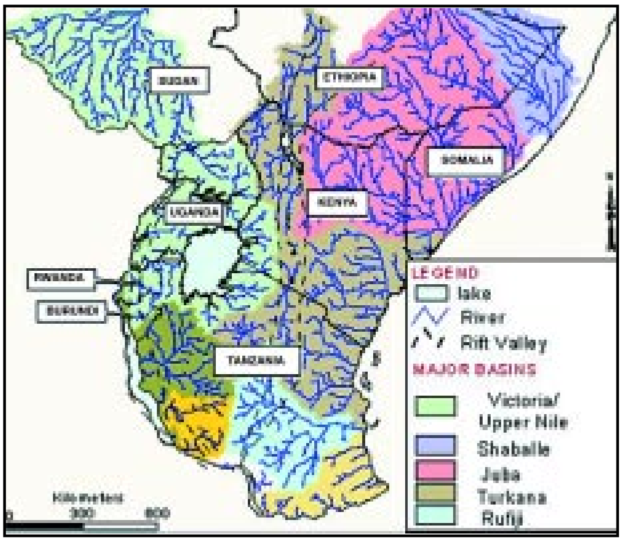

Figure 3.8: Major river basins and lake drainage areas of Eastern Africa

Physiography

Eastern Africa receives most of its rains from the monsoon system. The climate is equatorial, with a large variation in the distribution of rains from the Indian Ocean front towards Central Africa and from north to south, as a result of different altitudes and latitudes. Annual rainfall ranges from 255 mm in the drier areas in the north to 1,245 mm in the Lake Victoria Basin. Rainfall is highly unpredictable, both in terms of amounts from year to year and distribution within a given year. Persistent low rainfall in the region has resulted in persistent low water levels in rivers, reservoirs and aquifers, thus influencing the hydrology, biodiversity and use of water for domestic, industrial and irrigation purposes. Figure 3.9 shows the distribution of average seasonal rainfall over the Eastern Africa region during the four main seasons. Potential evapotranspiration generally exceeds the average seasonal rainfall.

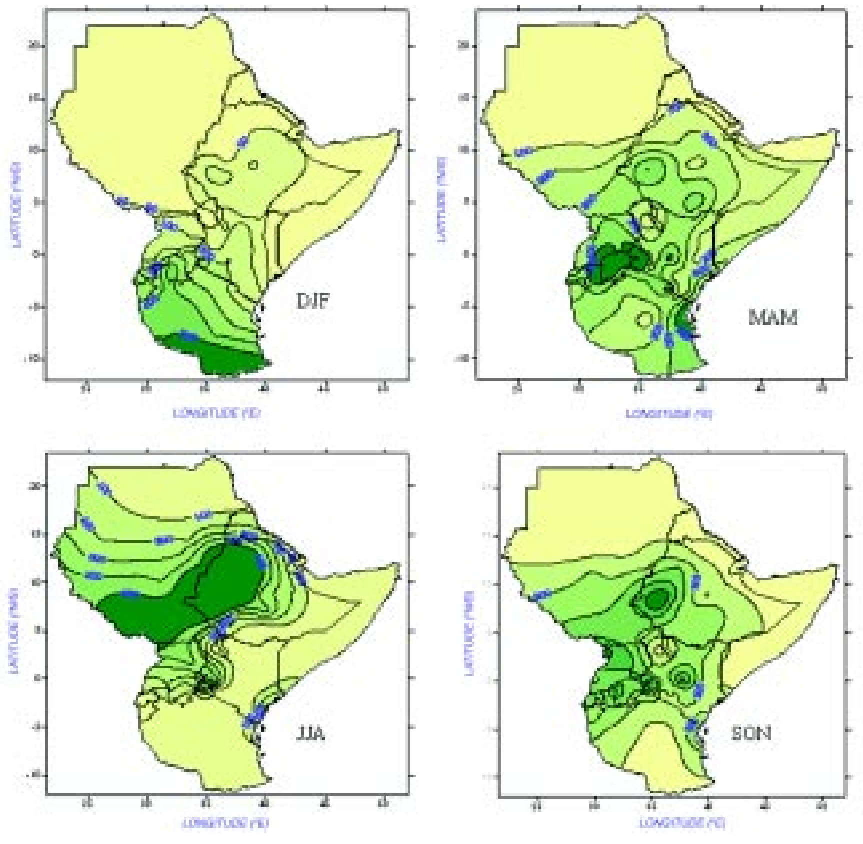

Figure 3.9: Distribution of seasonal rainfall over Eastern Africa

Eastern Africa is characterised by two fragile ecosystems: the mountains and hilly areas of Burundi, Rwanda, Uganda, Kenya and Ethiopia, and the semi-arid or arid (dryland) areas in Djibouti, Eritrea, Ethiopia and Somalia. These ecosystems support most of the region's population (with densities of more than 200 people/km^2), and are centres of crop cultivation. However, both these ecosystems have been seriously affected by deforestation due to urban and agricultural expansion. During the 1980s, Africa lost an estimated 47 million hectares of forest. By 1995, another 19 million hectares had been lost (FAO, 1997). Losses have been particularly high in countries such as Uganda where forest and woodland cover shrunk from an estimated 45% of the total land area in 1900 to only 7.7% by 1995 (Ministry of Natural Resources, 1995). Deforestation has changed the rate of rainfall infiltration and evaporation, soil moisture, and temperature conditions. Furthermore, due to increased sunlight, combined with nutrient enrichment in streams, Eastern African lakes are threatened by filamentous algae (favoured by schistosomiasis carrying snails) and weeds.

Surface water drainage in the Eastern African region is mainly controlled by the Great Rift Valley (Figure 3.8), which has an internal drainage. The area to the east of the valley drains its waters into the Indian Ocean, while the rest of the area forms the headlands and middle areas of the Nile River, which drains into the Mediterranean Sea. Freshwater resources in Eastern Africa are dominated by surface water with Lake Victoria as the largest source. Surface water resources are important for electric power generation.

The groundwater potential in the region is extremely variable, both spatially and temporally, in quality and quantity, and in the depth of the groundwater table. Recharge varies from less than 5% in the arid and semi-arid lands, where evapotranspiration losses are high, to 30% in areas of deep sandy soils and unconsolidated rocks, where evapotranspiration losses are low. In the humid and semi-humid regions recharge rates may be higher.

Vulnerability Indicator: Aridity and Water Availability

Eastern Africa has experienced at least one major drought each decade over the past 30 years. There were serious droughts in 1973/74, 1984/85, 1987, 1992/94, and in 1999/2000. There is evidence of increasing climatic instability in the region in terms of increasing frequency and intensity of drought (FAOSTAT, 2000).

Eastern Africa is fairly well endowed with fresh water, with a total average renewable amount of 187 km^3/yr (UNDP et al, 2000). Uganda has the largest share of this, with 39 km^3/yr (1,791 m^3/capita/yr) while Eritrea has the smallest, with 2.8 km^3/yr (data on per capita resources are not available; UNDP et al, 2000).

Vulnerability Indicator: Desertification

Long droughts, overgrazing and poor agricultural practices, deforestation and reclamation of wetlands for agriculture all contribute to desertification, even in the coastal areas of Eastern Africa. Ecosystem degradation (depletion of drinking water sources and degradation of vegetation) is also caused by the overstocking of animals associated with pastoralism.

Socio-Economy

The total population of Eastern Africa is estimated at 137 million (Table 3.2) and the average population growth of 3% is slightly higher than the sub-Saharan average of 2.9%. This growth ranges from 1.7% in the Seychelles to 3.8% in Tanzania. On average, 52% of the total population is under the age of 18 years. Population growth and human activities impact on the availability of water resources (see Figure 3.10 for the Kenyan situation), the state of aquatic ecosystems, and on the water quality.

Due to the high poverty levels in almost all rural areas, the region has experienced a large migration of people to urban centres in search of employment and better living standards. The region's unemployment rates are still very high. The few and isolated humid areas in Eastern Africa are extensively overpopulated and have resulted in the over-utilisation and degradation of land and forests, biodiversity loss, and the diminishing of freshwater resources – leading to increased water-use conflicts.

Table 3.2: Population sizes in Eastern Africa in 1999

Country	Population	Country	Population
Djibouti	434,116	Malawi	9,609,081
Eritrea	3,589,687	Somalia	6,590,325
Ethiopia	58,732,577	Tanzania	29,460,753
Kenya	28,803,085	**Total: 137,219,624**	

Source: http://library.advanced.org/thinkquest/tq-entries/16645/the_people/

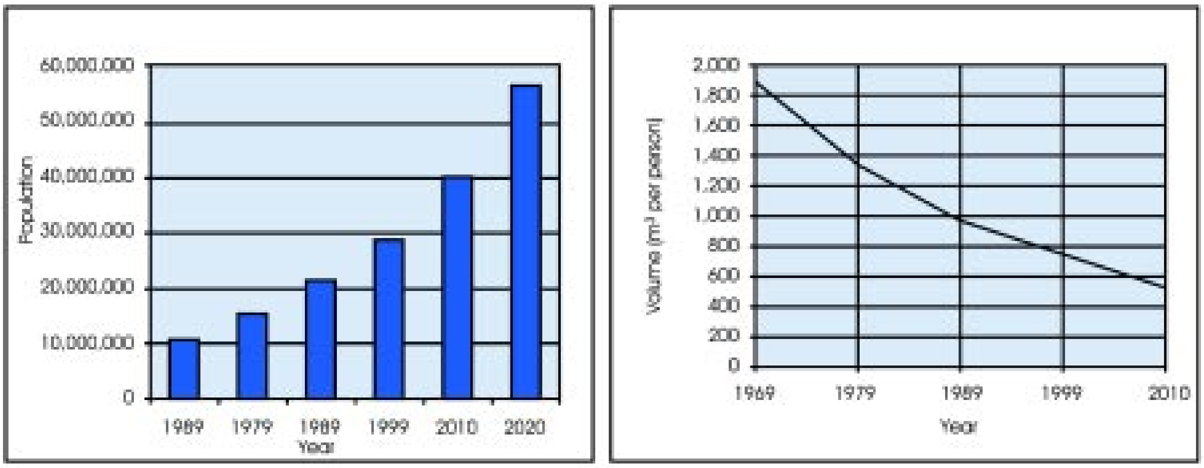

Figure 3.10: Population growth and per capita water availability in Kenya

(Source: Ministry of Water Development, Kenya - Water Master Plan, 1992)

While the average GDP growth rate of the group of Eastern African countries of Tanzania, Kenya, Uganda, Rwanda, Burundi, Djibouti, Eritrea, Ethiopia and Somalia increased from 2.8% in 1995 to 3.0% in 1996, to 3.9% in 1997, the weighted average GDP growth rate declined. This is indicative of the great disparity in performance trends between the different countries. Apart from factors such as the slump in the tourism trade and the decline in foreign investment and donor assistance, the overall economic performance of Eastern Africa is heavily dependent upon developments in the agricultural sector. Food production was particularly hard hit by erratic weather conditions and the El Niño phenomenon in 1997, demonstrating the region's high vulnerability to climate variability and change.

In many African countries HIV surveillance is now registering infection rates of 15-25% among adults, which are higher in urban areas but increasing in rural areas. Hardest hit is the working population aged from 15 to 45, with more women infected and at earlier ages than men. The impact of HIV/AIDS has overwhelmed communities and governments in Eastern Africa, destroying households, reducing business productivity, and crippling education and health services.

Vulnerability Indicator: Water Demand and Water Use

Annual freshwater withdrawals generally represent only a small percentage of the total available amounts, ranging from less than 3% of the total resources available in Burundi to 12% in Rwanda (UNDP, 2000). However, variability in rainfall results in demand frequently outstripping supply. Water for agricultural use will continue to command the highest demand. Domestic water demand will increase as a result of rapid population growth and urbanisation. In Uganda, for example, the per capita urban water use was 90 litres per day in 1980 and was expected to almost double by the year 2000 (NEMA, 1999). Countries expected to be experiencing severe water scarcity by 2025 are Ethiopia, Kenya and Somalia (AEO, 2002). Increased water stress, e.g. caused by prolonged periods of low rainfall and/or increased domestic/agricultural water demand, also affects countries that are dependent on hydroelectric power such as Tanzania, Kenya and Uganda. In 1999, for instance, increased domestic water demand in Uganda resulted in a drop in the power supply from the 162 MW capacity hydroelectric station at the Owen Falls Dam on the River Nile to its neighbour Kenya.

Vulnerability Indicator: Access to Water

The percentage of the population with access to safe drinking water in the region averaged around 40% over the period 1990-1996 (WHO/UNICEF, 2000).

Management

At a national level, water legislation exists in Ethiopia, Kenya, Tanzania and Uganda (Sharma et al, 1996). Responses to water stress include the revision of water resources development policies, improved reticulation and treatment, and greater involvement of stakeholders in water management and supply. Some examples are given below:

- Ethiopia initiated a process in 2001 to develop a sectoral strategic action plan for the realisation of the objectives of the national water policy. The strategy prioritises the interest and roles of different stakeholders, who are invited to make inputs to the strategy development;

- Kenya commercialised water supply and sanitation schemes in the Kericho, Eldoret and Nyeri pilot areas. These pilot studies will test whether privatisation contributes to meeting the goals of the Kenyan Water Act (Cap. 372), i.e. to enhance the provision, conservation, control, apportionment and use of fresh water;
- Tanzania's revised National Water Policy has been based on seven guiding principles, which include the recognition of water as a social, economic and environmental good, the 'polluter-pays' principle, and the basin approach in water resources planning and management;
- Uganda's long-term goal for the water sector is a system of full cost-recovery for services provided, but with the provision of cross-subsidised safe water services for low-income groups. A National Wetlands Policy was formulated and passed by the government in 1994, calling for capacity building for wetlands management, public awareness and wetland resource assessment.

Governments recognise that the problems of water stress are not confined solely within their borders. Issues related to the management of international waters are addressed at various forums and several regional bodies have been formed for such purposes. Major international programmes for water resource management in the region include the Lake Victoria Environmental Management Programme (LVEMP) and the Nile Basin Initiative (NBI; see Section 3.4):

- The LVEMP was established in 1995 with a focus on the creation of baseline data and information and for the guidance of future action plans, especially in the areas of fisheries management, pollution control, control of invasive weeds, and catchment land-use management. The first phase of the programme was seen as a first step in a long process that should lead to improvements in the sustainable use of natural resources in the Lake Victoria Basin. Achievements to date include the biological control of water hyacinth *(Eichornia crassipes)*, the involvement of local communities in fisheries research and management, and afforestation initiatives in the lake catchment. Priority areas of focus for the second phase have been identified as socio-economic development, management and research, and major transboundary issues such as the inflow of water hyacinth, and siltation and deforestation associated with the upstream counties of Rwanda and Burundi;
- In the last decade, efforts towards cooperation on the Nile have intensified and, in 1993, the Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile Basin (TECCONILE) was established with the aim of promoting a development agenda. A transitional mechanism for cooperation was officially launched by the Council of Ministers of Water Affairs of the Nile Basin States (Nile-COM) in Dar es Salaam in February 1999. The process was officially named the Nile Basin Initiative (NBI) later that year, and in November 2002 a secretariat was established in Entebbe, Uganda. Within this framework, plans are being designed to harness the basin's waters for irrigation, and for the establishment of an energy policy to provide power to all the countries in the region. Some NBI projects, including those aimed at harnessing energy and those designed to make the best use of fisheries resources, are nearing their implementation stage.

Vulnerability Indicator: Sector Reform
There has been some progress in water sector reforms in Eastern African countries, which will create an enabling environment to mitigate against the adverse effects of environmental change on water resources. Stakeholder engagement, including communities' responses to water stress, will be critical in this context.

3.2.1 Lake Victoria Basin

Lake Victoria Basin is located in the upper reaches of the Nile River Basin and has a surface area of about 253,000 km^2, of which 46% lies in Tanzania (URT, 1995). The remainder of the area is shared between Kenya, Uganda, Rwanda and Burundi (Figure 3.11). Lake Victoria itself is the largest freshwater lake in Africa and the second largest lake in the world. The lake occupies three countries, Kenya, Uganda and Tanzania, and draws its waters from the Gucha, Grumeti, Kagera, Mara, Migori, Nyando, Nzoia, Simiyu and Sondu Rivers, of which the Kagera is the main contributor. The catchment area is surrounded by mountains except to the north. Box 3.3 summarises the main characteristics of Lake Victoria Basin.

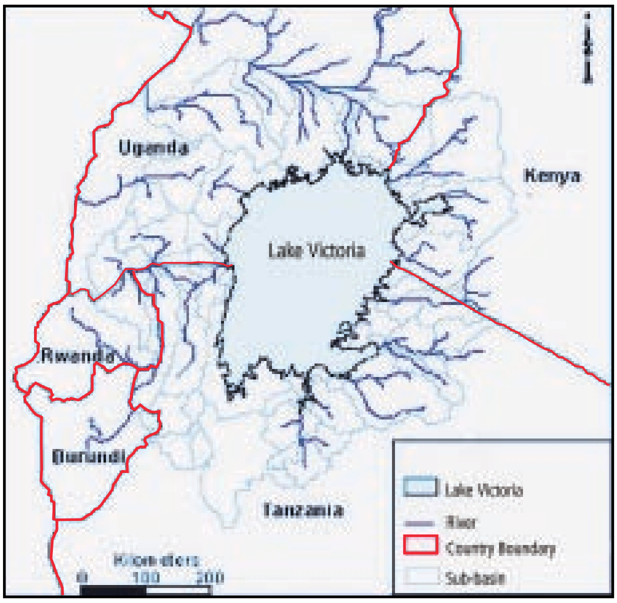

Figure 3.11: Lake Victoria Basin: riparian countries and sub-basins

Box 3.3: Lake Victoria Basin – Main characteristics

Victoria Basin		**Water Use**
Surface area:	252,800 km^2	Agriculture
Lake area:	68,800 km^2	Industry
MAP:	450 – 2,450 mm/a	Domestic
		Fisheries
		Hydropower
		↑ Increasing
Demography		
Population:	30 million	
Density:	165 persons/km^2	
Major Dams		**Vulnerability**
Owen Falls		Climate variability and change affects catchment environment

Source: Water Resources Division, Ministry of Water and Livestock Development, Tanzania

Physiography

Annual rainfall in the Lake Victoria area varies between 950 and 2,450 mm. In the terrestrial part of the basin, annual rainfall ranges from 450 to 950 mm. Rainfall is generally erratic. Historical records indicate the occurrence of an extraordinary pluvial period from 1961-64 in the eastern part of the basin, when the level of the lake rose by 2.5 metres and discharge from the Rivers Nyando and Sondu Miriu were 10 to 20 times higher than their 35-year decadal averages. About 85% of the water entering Lake Victoria originates from rainfall directly on the lake surface, while the remainder originates from rivers that drain the surrounding catchment. Some 85% of the lake's water is lost to evaporation. Surface water drainage from the lake is mainly through the Victoria Nile near Jinja in Uganda, via Owen Falls, Lake Kioga and the Murchison Falls.

Cropland occupies 40.3% of the basin, while grassland, savannah and shrubland account for 37% and wetlands for 40.8% (WRI, 1998). Lake Victoria's wetlands are among the most productive systems in the region and are vital to local and regional socio-economic development and biodiversity. Recent modifications in land use, overexploitation of the resource base and demographic changes are threatening to undermine the integrity of the lake's ecosystem. Potential effects include latitudinal and altitudinal shifts in plant and animal species, as well as the loss of biodiversity due to water scarcity.

Since Lake Victoria arose from a dry landscape 14,600 years ago, it has experienced the rapid evolution of endemic species of cichlid fish, providing one of the most diverse flocks of fish species on earth (Johnson et al, 2000). By the 1980s, however, some 400 endemic species were threatened with extinction (Witte et al, 1992). Pollution from agricultural activities since the 1930s and the introduction of Nile Perch into the lake in the 1950s are some of the reasons given. In addition, the rapid expansion of the water hyacinth weed has been attributed to nutrients from agricultural drainage, industrial discharge, and poorly treated sewage effluent.

There have not been severe droughts in the lake area except for northern Uganda and some parts of southern Sudan. Flooding in the basin is mainly confined to the foothills of the highlands and to the plains just before the rivers enter the lake. Most of the plains are characterised by the presence of swamps, which are vital in regulating both the quality and quantity of river flows. In areas where swamps have been drained and the resident river canalised, perennial flooding occurs such as on the Kano Plains near the outlet of Kenya's River Nyando. The Owen Falls Dam and Lake Kioga with its swamps are efficient in regulating the outflow of Lake Victoria.

Since the 1960s, Lake Victoria has experienced a serious decline in water quality, negatively impacting on dependent communities. The deep waters of the lake are depleted in oxygen for longer periods of time, and filamentous and colonial blue green algae now dominate the lake's algae community (Odada et al, 2002). Major pollution sources are sewage effluents from towns, urban centres and agricultural activities:

- Several municipalities, towns and urban centres on the shores of Lake Victoria and in the catchment areas discharge untreated sewage into the lake due to the lack of treatment facilities. Pollutants emanating from local industries are also discharged into the lake;
- Poor agricultural practices, the unregulated application of agro-chemicals, and high rainfall all combine to produce runoff laden with pollutants discharging into the aquatic ecosystems. Sediment and nutrient loads arising from the catchment are responsible for the proliferation of water hyacinth as well as algal booms in Lake Victoria, indicating a close interrelationship between the catchment and the lake system.

The pollution status of the water poses a major threat to the social status of people living in Lake Victoria Basin. Given that the present poverty situation is already severe, with well over 50% of the population living below the poverty line, increasing water stress and pollution may further aggravate the precarious socio-economic situation in the future.

Socio-Economy

Lake Victoria Basin supports one of the densest and poorest rural populations in the world, with densities of up to 1,200 persons/km^2 in parts of Kenya (Hoekstra and Corbett, 1995). The average density in the basin is 165 persons/km^2. This is due to its favourable conditions for agriculture, fishing and other economic activities. The growing population (average annual growth rate is 3%) is increasing water demand for domestic use, food security and industry. Such increases can reach the point where the requirements will outstrip natural supply. The lake basin is also highly urbanised, and on its shores in all three countries large cities and towns are growing fast.

Many developments are geared towards exploiting the lake catchment's resources, including water, fish, minerals and land. Fishing is by far the most important economic activity in the region; in recent years, the emergence of a lucrative Nile Perch fillet export market to Europe has turned the sector from a source of subsistence livelihood into a competitive commercial activity in the riparian countries. The fisheries sector contributes about 3% of the GDP of Tanzania's and Uganda's economy, and 0.5% of Kenya's GDP (Bwathondi et al, 2001; URT, 2002). The estimated landings for the lake in the late 1980s and 1990s were about 500,000 metric tonnes per year (Odada et al, 2002). Despite this, the annual Gross Economic Product (GEP) of the lake region remains relatively low: in the order of US$ 3-4 billion (or US$ 107-143 GEP per capita), ranking the riparian countries among the world's poorest on a per capita income basis.

Cholera and bacillary dysentery have become endemic among the lake populations in recent years.
A case-control study conducted at seven sites in the Asembo region, a rural area bordering Lake Victoria, found drinking water from the lake to be one of the independent risk factors for illness. Geographic analysis showed that diarrhoeal patients who had cholera were more likely to live in a village bordering the lake than were those with other pathogens identified (Shapiro et al, 1992).

Management
Multi-sectoral frameworks are being developed to facilitate Integrated Water Resources Management involving stakeholders from the water, agricultural and industrial sectors. With the recent ratification advancements of the East African Community Treaty, the scope for regional institutions to manage shared ecosystems has been expanded and facilitated. Examples include many non-governmental and inter-governmental institutions such as ACTS, IUCN, AWF, WWF, LVEMP, NBI, Nile/FRIEND, etc. A Memorandum of Understanding on the Environment may soon be implemented by the three riparian countries. The various sector committees under the East African Community's environment desk are set out to handle various technical aspects such as environmental standards, which will be binding in the respective countries. This will be a crucial focal point for launching transboundary initiatives.

3.2.2 Rufiji River Basin

The Rufiji River Basin is the largest river basin in Tanzania, with a total surface area of about 180,000 km^2 (Figure 3.12 and Box 3.4). The Rufiji River originates in the Southern Highlands where the Great Ruaha River and the Usangu wetlands are found. The importance of the Usangu catchment cannot be overemphasised. Although it represents only 12% of the total Rufiji catchment area, it provides 56% of the runoff to the Mtera reservoir through the Ruaha River (GOT, 2000).

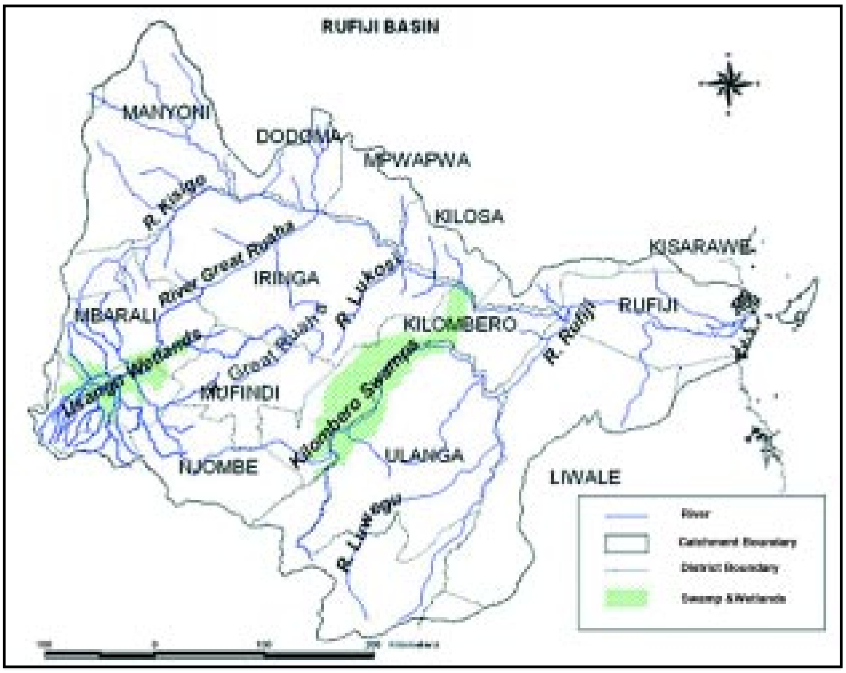

Figure 3.12: Rufiji River Basin

Physiography
The average annual rainfall ranges from 1,550 mm in the southeastern parts of the Rufiji Basin to 450 mm in the northern parts. Whereas annual rainfall variability in the basin is up to 10%, evapotranspiration varies up to 20% (Arnell, 1999).

Grassland, savannah and shrubland together cover 77.4% of the basin, dryland 20.4%, and cropland 19.7%. The coverage of wetlands is only 7.8% (GOT, 2000).

Agricultural development (irrigation) has been responsible for the reduced flooding and subsequent degradation of the Usangu wetlands and plains, and for a reduction in grazing capacity. Other reasons for reduced river flows include increased population pressure, land-use changes (rapid expansion of both rain-fed and irrigated agriculture), and increased cattle on the Usangu plains (GOT, 2000). Human-induced activities mostly occur upstream of the Rufiji River. These changes adversely affect the fish population of the wetlands and rivers, and disturb seasonal animal migrations in Ruaha National Park. The continuing degradation may ultimately prevent the wetlands from carrying out their river-flow regulation function.

Box 3.4: Rufiji River Basin – Main characteristics

Basin:		**Water Use**	
Surface area:	178,660 km^2	Agriculture	↑
MAP:	950 mm/a	Hydropower	Increasing
		Domestic	
		Fishery	
		Mining	
Demography			
Population:	3.4 million		
Density:	19 persons/km^2		
Major Dams		**Vulnerability**	
Mtera:	3,200 Mm^3 (80 MW)	Climate variability and change affects catchment environment;	
Kidatu:	125 Mm^3 (204 MW)	Competing users	

Source: Water Resources Division, Ministry of Water and Livestock Development, Tanzania

From a hydrological point of view, the most significant change in the basin has been the reduction in the dry-season flow of the Great Ruaha River since the early 1970s. Note that according to the Sustainable Management of the Usangu Wetland and its Catchment project (SMUWC, 2001), analyses of flow records do not indicate significant changes in either total or wet-season flows downstream of Usangu. Cessation of the Ruaha River flow in the Ruaha National Park has frequently occurred since 1993, with a progressively expanding dry season.

There is the potential risk of water pollution through waste disposal from sugar industries in Kilombero and the use of fertilizers in cultivated areas in Mbeya and Iringa (URT, 1995). The few studies that have thus far been undertaken on surface and groundwaters of the Usangu catchment have not yet revealed evidence of pollution (GOT, 2000).

An example of a water supply infrastructure project to alleviate water shortages is the major urban water supply project for Dar City at the downstream end of the basin. Currently, Dar City's water supply is vulnerable as it is solely dependant upon the Ruvu River. It is the water authorities' intention to ensure an adequate and continuous water supply by abstracting water from two different sub-basins, each of them within different climatic regimes.

Socio-Economy

Projections for 2006 show that the Rufiji Basin will have 4.1 million people, compared to 3.4 million in 2002. Annual population growth in the Usangu catchment has amounted to 11.1%, averaged over a period of about 50 years, since 1948 (GOT, 2000). The growth rate was highest in the Mbeya rural areas, where the population grew by 132% during 1988-2002. Such significant population growth has major implications for local water resources.

Irrigation farming and livestock herding are by far the most significant economic and water- consuming activities in the Rufiji Basin. Although most of the hydroelectric power for Tanzania is produced in the basin, there are no major industrial urban centres and industrial activity is relatively limited.

Irrigated farming is most prevalent in the Usangu catchment and the Kilombero Valley. Water-use efficiency for irrigation is generally lower than 30%. Rice is one of the main crops produced in the Usangu area, where irrigation coverage has grown from 3,000 hectares in 1958 to over 40,000 hectares today. In Kilombero, an area of a similar size was irrigated for growing crops such as rice and sugarcane using about 600 mm and 1,200 mm of water per season respectively in 1995, which translated into a 20% water-use efficiency level.

Livestock rearing is also a major water-consuming activity. The livestock population reached its peak in the mid-1970s at 540,000 head, and has since declined to an estimated 366,000 animals, of which 76.5% are cattle. Pastoralists who migrated here from Shinyanga, Arusha and other regions have settled on the Usangu plains, where some, particularly the Sukuma, are also engaged in farming.

Hydroelectric power is generated at the 200 MW Kidatu Dam just before the Great Ruaha River enters the Kilombero Valley, and at the 80 MW Mtera Dam situated upstream. The reduction in dry-season flows has had a far-reaching impact nationwide through power-rationing problems due to inadequate levels in the Mtera reservoir since 1995.

The positioning of irrigation projects along the Great Ruaha River upstream of the Mtera and Kidatu power stations is likely to continue to lead to high competition for water between irrigators and hydropower stakeholders (URT, 1995). Competition for land and water has also manifested itself between pastoralists and farmers in the Usangu area, particularly in the Utengule swamps. The expansion of cultivated areas, and corresponding shrinkage of pastureland, clearly calls for an integrated approach to the future development and management of the area's water resources.

Management
A new National Irrigation Master Plan was formulated by the Ministry of Agriculture to increase the efficiency of water use for irrigation and at the same time increase the acreage of irrigated farmland to ensure food security in the Rufiji Basin. Water demand for irrigation will thus continue to rise, increasing water stress in the area. The situation is expected to worsen further when climate variability and change are taken into account.

3.2.3 Comparison of Lake Victoria and Rufiji River Basins

A brief summary of the main aspects of water resource vulnerability for the Lake Victoria and Rufiji River Basins is presented in Table 3.3 below.

Table 3.3: Water resource vulnerability in Lake Victoria and Rufiji River Basins

Cluster	Vulnerability Indicator*	Lake Victoria Basin	Rufiji River Basin
Physiography	**Aridity**	Rf: 450 - 2,450 mm/yr	Rf: 450 - 1,550 mm/yr
	Water availability	1,700 - 4,000 m^3/person/yr	6,466 m^3/person/yr
	Storage and supply infrastructure	No major dams	Major dams in place
Socio- Economy	**Population density**	165 persons/km^2	19 persons/km^2
	Access to safe water	~40% of total population of Eastern Africa	
	Water use	Less irrigation	Irrigation more developed
	Poverty	Higher level	Lower level
	Conflicts	Less conflicts	Irrigators vs. hydro-power generation
Management	**Sector reform**	Ongoing	Ongoing
	Implementation and adaptive capacity	Many stakeholders involved	Fewer stakeholders involved
	Data availability, gaps and quality	More developed	Less developed

Physiography
- Neither of these river basins can be classified as arid or semi-arid, with annual rainfall in the Lake Victoria Basin varying from 450 to 2,450 mm and in the Rufiji River Basin from 450 to 1,550 mm. Except for northern Uganda and southern Sudan, there have not been any severe droughts in the Lake Victoria area. Records even indicate the occurrence of an extraordinary pluvial period from 1961-64, when lake levels rose by 2.5 metres and river flows increased by 10-20 times. About 85% of the water entering Lake Victoria originates from rainfall directly on the lake surface, while the remainder comes from rivers that drain the surrounding catchment. Some 85% of the water leaving the lake is by evaporation.

- Wetlands in the Lake Victoria Basin are among the most productive systems in the region and are vital to local and regional socio-economic development and biodiversity. Recent modifications in land use, overexploitation of the resource base and demographic changes are degrading the ecosystem integrity. Irrigated agriculture in the Rufiji Basin is responsible for reduced flooding and degradation of the Usangu wetlands and plains, and is also responsible for a reduction in grazing capacity.
- Lake Victoria has experienced a serious deterioration in water quality since the 1960s, mainly due to sewerage effluents from towns and urban centres and poor agricultural practices. In the Rufiji Basin there is the potential risk of water pollution through waste disposal from sugar industries and the use of fertilizers in cultivated areas.

Socio-Economy

- The average population density in the Lake Victoria Basin is much higher than that in the Rufiji River Basin. This is due to the favourable conditions for agriculture, fishing and other economic activities. However, the growing populations in both basins are increasing water demands for domestic use, food security and industry. Such increases can reach the point where requirements will outstrip the natural supply. Lake Victoria Basin in particular is becoming highly urbanised.
- Cholera and dysentery have become endemic among the Lake Victoria populations in recent years.
- Drinking water from the lake was found to be one of the independent risk factors for illness.
- Fishing is by far the most important economic activity in the Lake Victoria region. In the Rufiji River Basin, irrigation farming and livestock rearing are by far the greatest economic and water-consuming activities. Although most of the hydroelectric power of Tanzania is produced in the Rufiji River Basin, industrial activity here remains relatively low.
- Of the two basins, Lake Victoria experiences a higher degree of poverty. The riparian countries of the lake basin are ranked among the poorer countries worldwide on a per capita income basis (annual GEP: US$ 107-143 per capita).
- There is little evidence of conflict from the use of water resources in Lake Victoria. Conflicts in the Rufiji River Basin may result from the high competition for water between irrigators and hydropower stakeholders.

Management

- Multi-sectoral frameworks are being developed to facilitate Integrated Water Resources Management involving stakeholders from the water, agricultural and industrial sectors.
- The scope for regional institutions to manage shared ecosystems in Lake Victoria Basin has been expanded and facilitated with the recent ratification advancements of the East African Community Treaty. The various sector committees under the East African Community's environment desk are a crucial focal point for launching future transboundary initiatives.
- A new National Irrigation Master Plan was formulated for the Rufiji River Basin by the Ministry of Agriculture to increase the efficiency of water use for irrigation and at the same time increase the acreage of irrigated farmland to alleviate poverty. Water demand for irrigation and water stress will continue to rise – a situation that is expected to worsen further when climate variability and change are taken into account.

Water Scarcity

- Ethiopia, Kenya and Somalia are among those countries expected to experience severe water scarcity by 2025 (AEO, 2002). Increased water stress, e.g. caused by prolonged periods of low rainfall and/or increased domestic/agricultural water demand, also affects countries that are dependent on hydroelectric power such as Kenya and Uganda. Recent modifications in land use, overexploitation of the resource base, and demographic changes could lead to water scarcity, especially in the Lake Victoria region.

3.3 Western Africa

The countries of Western Africa (Figure 3.13) share abundant similarities, not merely in relation to their developing socio-economic status, but to their geology, physiography, demography, culture and history. Several characteristics recur from one country to another: a young population, rapid and uncontrolled urbanisation, domination by the agricultural sector, slow human resources development, poorly developed water and sanitation systems. Demand for fresh water comes mainly from agriculture, followed by domestic and industrial uses. Although non-consuming, hydroelectric power production necessitates major water storage, leading to high evaporation at exposed dam sites.

There are also contrasts among the countries, which will be discussed in subsequent sections. There are 16 countries within the region, of which:

- Twelve are coastal countries: Benin, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mauritania, Nigeria, Senegal, Sierra Leone and Togo;
- Three are landlocked countries: Burkina Faso, Mali and Niger; and
- One is an island state: Cape Verde.

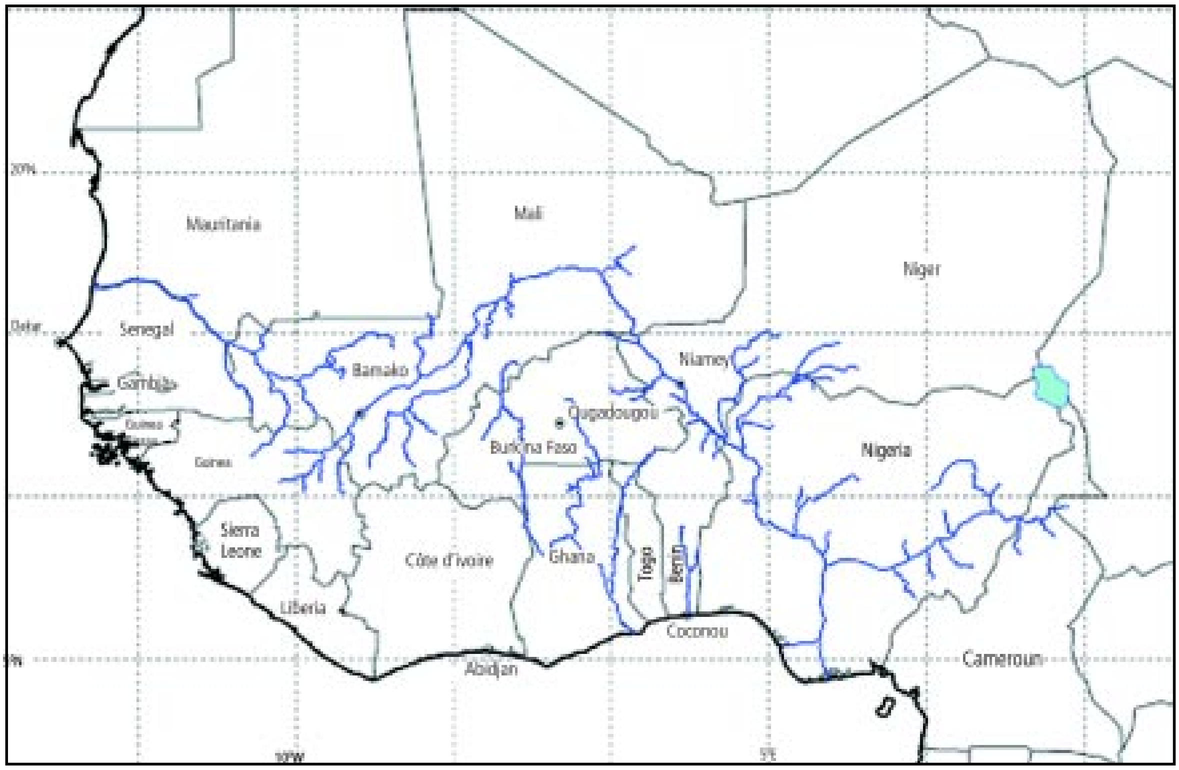

Figure 3.13: Western African region with Senegal and Niger Rivers

Western Africa has a large number of river basins, 11 of which are transboundary, i.e. shared by at least two countries. The most important of these are the Niger, Senegal, Volta, Gambia and Lake Chad Basins. The Senegal and Niger River Basins will be considered for a more detailed vulnerability assessment.

Physiography

The climates in the region range from humid equatorial conditions at the coast to arid conditions in the northern Sahelian countries. Rainfall varies from less than 200 mm/year in the arid zone to more than 1,000 mm/year in the tropical zone. Inter-annual variation is very high. All over the Sahel, a decrease in rainfall has been observed over the last three decades (1970-2000).

The potential evapotranspiration amounts to 1,300 mm/year in the humid regions and increases to about 2,000 mm/year around latitude 20°N. The actual evaporation is higher in the region of higher rainfall and decreases to nearly zero in the region of minimum rainfall in the Sahara Desert. The potential and actual evapotranspiration follow the same pattern as the actual evaporation. Generally, the annual surplus of water decreases northward and rapidly turns into an annual deficit of water in the region under latitude 10°N and between 10°N and 20°N. The water deficit becomes more acute in the Sahara, between latitudes 20°N and 30°N.

Western Africa's ecosystems are vulnerable to environmental change for the following reasons:

- Adverse climate changes have further reduced the already low productivity of the arid lands of the Sahel;
- Population growth has significantly increased the per capita pressure on natural resources;
- Lack of technological innovation has led to unsustainable land management practices;
- Poverty is limiting the population's potential to address the degradation effectively; and
- Lack of efficient governance is constraining the possibilities for governments and other stakeholders to address the issues.

Table 3.4 shows water use and requirements for the agricultural sector in the Senegal, Niger and Lake Chad Basins.

Table 3.4: Present water use and potential water requirements for West African agriculture

Basin	Total area (km^2)	Mean Rainfall (mm/yr)	Irrigation Potential (ha)	Area under Irrigation (ha)	Total Water Use (km^2)	Actual water use as % of potential water requirement
Senegal	483,181	550	420,000	118,150	2.67	18.6
Niger River*	2,273,946	690	2,816,510	228,240	2.43	4.4
Lake Chad	2,381,635	415	1,163,200	113,296	1.00	6.0

***Note that the active drainage area is less than 50% of the total basin area.**

Surface water resources in the region include rivers, lakes and wetlands. The major rivers flow over more than one hydro(geo)logical region and are transboundary, making it imperative for riparian states to cooperate in water resource assessments. The Niger River Basin involves nine of the 16 countries, including Cameroon and Chad, while the Senegal River Basin is shared by four countries, and the Volta Basin is shared by five countries. Most of the rivers discharge into the Atlantic Ocean. The mean annual runoff of the region's major rivers is presented in Table 3.5 (Ayibotele, 1993).

Table 3.5: Mean annual runoff of major rivers in Western Africa

Rivers	Drainage area (km^2)	Mean annual runoff (millions m^3)
Niger-Benoue	1,215,000	221,500
Senegal	338,000	21,800
Volta (at Senchi)	394,100	39,735
Gambia	77,850	5,050
Mono	22,000	3,375

River runoff decreases in a northern direction. Water is most abundant between August and October, when 40-70% of the annual runoff occurs. Southward, in the sub-humid parts of the tropical zone, 5-6 months account for 80% of the annual runoff, whereas in the humid zones there is an even distribution of runoff during the year with two peak maxima observed (Ayibotele, 1993); about 80% of the mean annual runoff occurs within 8-9 months.

The sub-Saharan drought of the early 1970s had serious consequences for the water resources of Western Africa. Analyses of the monthly rainfall data for the whole region by Le Barbe and Lebel (1997) showed that the dry period was characterised by a decrease in the number of rainy events, while the mean storm rainfall varied little. A deficit of 10-30% in rainfall generally leads to a deficit of 20-60% in river discharge. The Niger River, the largest river in Western Africa, actually dried up for several weeks at Malanville in the Benin Republic in 1985. This was the consequence of a one-year lag of the lowest rainfall and runoff (1984) recorded since the beginning of the century in the upper basin.

The groundwater potential of the Western African region is determined by three major types of aquifers, namely basement aquifers, deep coastal sedimentary aquifers, and superficial aquifers. The availability of groundwater depends upon the type of substrate and varies according to the amounts of precipitation and infiltration. In the arid and semi-arid zones, large and deep aquifers are often present in large sedimentary basins, mostly in the form of fossil aquifers. In humid and sub-humid regions, the groundwater is dominated by Precambrian crystalline formations and by large sedimentary formations.

Large aquifers in sedimentary basins have warranted large-scale studies because of their geographical extension and water storage, but their exploitation is rarely rigorously controlled. The coastal sedimentary formations consist of some very productive sandstone and limestone layers. Yields averaging 18 m^3/hr are obtained from these types of aquifers in Côte d'Ivoire, Togo, Togo-Benin and Benin. Discontinuous (basement) aquifers have been the subject of rapid assessments and development of methodologies to increase the rate of success in establishing productive boreholes and wells. Their exploitation is always limited and depends mainly on the means used to abstract the water and on the variation in the piezometric levels. Borehole and well yields are generally low and range from 0.3 to 3 m^3/hr but can reach 10 m^3/hr. In some areas, yields as high as 45 m^3/hr have been observed.

There is great concern about the quality of water in the region. Even when perennial surface water is available, its consumption in an untreated state presents a serious risk for human health because it is frequently contaminated by pathogens. The issue of groundwater quality and pollution has not been adequately addressed, largely because of insufficient sampling and analyses. It is, however, known that groundwater in some countries (e.g. Senegal and Ghana) contains iron concentrations above the permissible limits.

Vulnerability Indicator: Aridity and Water Availability

Western Africa's water resources are characterised by extreme variability both over space and time. Some of the countries are well endowed with water resources while others face serious scarcity problems. And while drought has been a common feature of the Sahelian Zone since the 1970s, floods periodically affect the coastal belt. In conclusion, the region is characterised by a high degree of vulnerability as a result of natural climatic variation, combined with an anticipated increase in the unpredictability of precipitation variability and increasing demand from the rapidly growing population.

Socio-Economy

The total population of the region in 1995 was over 227 million inhabitants, with an average density of 32.4 persons/km^2 (GWP, 2000). The highest population density is found in Nigeria (109.3 persons/km^2) and the lowest in Mauritania (2.2 persons/km^2). The growth rate is over 3% per year and infant mortality per 1,000 births varies from 32 to 149, with an average of 102. Life expectancy at birth varies from 45 to 68 years, with an average of 51 years. For the region as a whole, 41-49% of the population is below 15 years of age. The rate of urbanisation is high in all countries, with urban populations accounting for 50% of the total in some areas, especially along the coast. The total population of Western Africa is expected to exceed 500 million by 2025 (see Table 3.6).

The region's economy is dominated by rain-fed agricultural activities, mainly for nutritional self-sufficiency. The region produces several primary commodities for export, including cocoa, coffee, minerals, oil and timber, and its earnings are therefore subject to global price fluctuations. Annual per capita incomes vary significantly, from US$ 1,000 in Cape Verde to US$ 200 in Liberia. Western African countries rank between the 123rd and 175th countries on the UNDP Human Development Index.

Vulnerability Indicators: Water Demand and Water Use

Demand for water has been steadily increasing in all sectors as a result of population growth, commercial agriculture and industrial expansion. Total withdrawal of water for domestic, industrial and agricultural consumption was estimated at 11.4 billion m^3 in 2000 (GWP, 2000). The per capita water demand in rural areas in 1995 ranged from 15-35 litres per day in Guinea to 45 litres per day in Mali. For urban supplies, it ranged from 40-50 litres per day in Burkina Faso to 100-110 litres per day in Senegal.

Vulnerability Indicator: Access to Water and Sanitation

Water supply coverage was 40% in rural areas and 64% in urban areas in 1995, while sanitation coverage was 25% in rural areas and 59% in urban areas (GWP, 2000). The socio-economic consequences of low water supply and sanitation coverage include an increased incidence of waterborne and water-related diseases, such as malaria, guinea-worm, cholera, typhoid and bilharzia.

Management

Basin organisations have been established for the Niger, Senegal and Gambia Rivers and for Lake Chad. In the case of the Volta River, an informal arrangement for consultation has been made between Ghana and Burkina- Faso.

Cross-Cutting Vulnerability Indicators

Six Western African countries are expected to experience water scarcity by the year 2025, namely Benin, Burkina Faso, Ghana, Mauritania, Niger and Nigeria. Most of the other countries are now also constrained by inadequate water supplies. Climate change scenarios predict reduced rainfall and increases in evaporation in most parts of the region. More specifically, an increase in the rate of desertification is predicted for the Sahelian zone (IPCC, 2001). Countries in the coastal zone are expected to experience more intense rainfall and increased runoff. If this prediction is combined with the existing high rate of deforestation and ecosystem degradation, this could have serious consequences for soil erosion, agricultural production and self-sufficiency. Table 3.6 shows the different degrees of vulnerability facing the countries of Western Africa.

Although closely linked to low rainfall, water scarcity, stream flow and other vulnerability indicators do not necessarily coincide with the period of rainfall shortage because of the complexity of the processes that transform precipitation into stream flow and also because of man-made measures, such as flow control, diversion and storage. It is usually assumed that the combination of adverse climatic conditions and human activities in Western African is the main cause of desertification of vulnerable arid, semi-arid and dry sub-humid areas. In this process, the soil structure and soil fertility are degraded and bio-productive resources decrease or disappear. The United Nations Convention to Combat Desertification refers to 'arid', 'semi-arid' and 'dry sub-humid' areas where the ratio of annual precipitation to potential evapotranspiration falls within the range of 0.05 to 0.65 (Sehmi and Kunzewicz, 1997).

Table 3.6: Water resources and per capita annual water availability

	Population (10^3)				Annual Renewable Water (km^3)	Water Availability per Capita per year (m^3)			
Country	**1995**	**2005**	**2015**	**2025**		**1995**	**2005**	**2015**	**2025**
Benin	5421	7486	10065	12587	25.8	4800	3400	2600	2000
Burkina Faso	10396	14080	18222	23710	17.5	1700	1200	900	700
Cote D'Ivoire	14535	21218	30069	39334	77	5300	3700	2600	2000
Cape Verde	438	595	757	922					
Gambia	954	1271	1593	1864	8.0	8130	6240	5020	4090
Ghana	17608	23845	29884	35442	53.2	3020	2230	1780	1500
Guinea	6700	9162	12252	15273	226.0	3370	2470	1840	1480
Guinea-Bissau	1073	1338	1649	1918	27	25160	20180	16370	14080
Liberia	3032	4207	5689	7245	232	76520	55150	40780	32020
Mali	10799	14885	19918	24774	100	9260	6720	5020	4040
Mauritania	2335	3129	4129	5119	11.4	4880	3640	2760	2230
Niger	9104	12694	17167	21482	32.5	3600	2560	1840	1510
Nigeria	127694	174307	228753	280890	280	2190	1610	1220	1000
Senegal	8423	11172	14269	16988	39.4	4680	3530	2760	2320
Sierra Leone	47240	6250	8161	10045	160	33760	25600	19610	15930
Togo	4138	5711	7750	9842	12	2900	2100	1550	1220
TOTAL	**227426**	**311360**	**410942**	**507455**	**13025**	**51730**	**4100**	**3130**	**2570**

Adapted from: West African Water Vision (GWP-2000) and West African Conference on IWRM (Oct-2003)

3.3.1 Senegal River Basin

The Senegal River has its main source in the Fouta-Djalon Mountains in Guinea and provides water to the semi-arid parts of Mali, Senegal and Mauritania. The basin has a total area of ~483,000 km^2 and the river course is 1,800 km long (Figure 3.14). Mauritania has the largest area of the basin with 50%, followed by Mali with 35%, Senegal with 8%, and Guinea with 7%. Box 3.5 summarises the main basin characteristics.

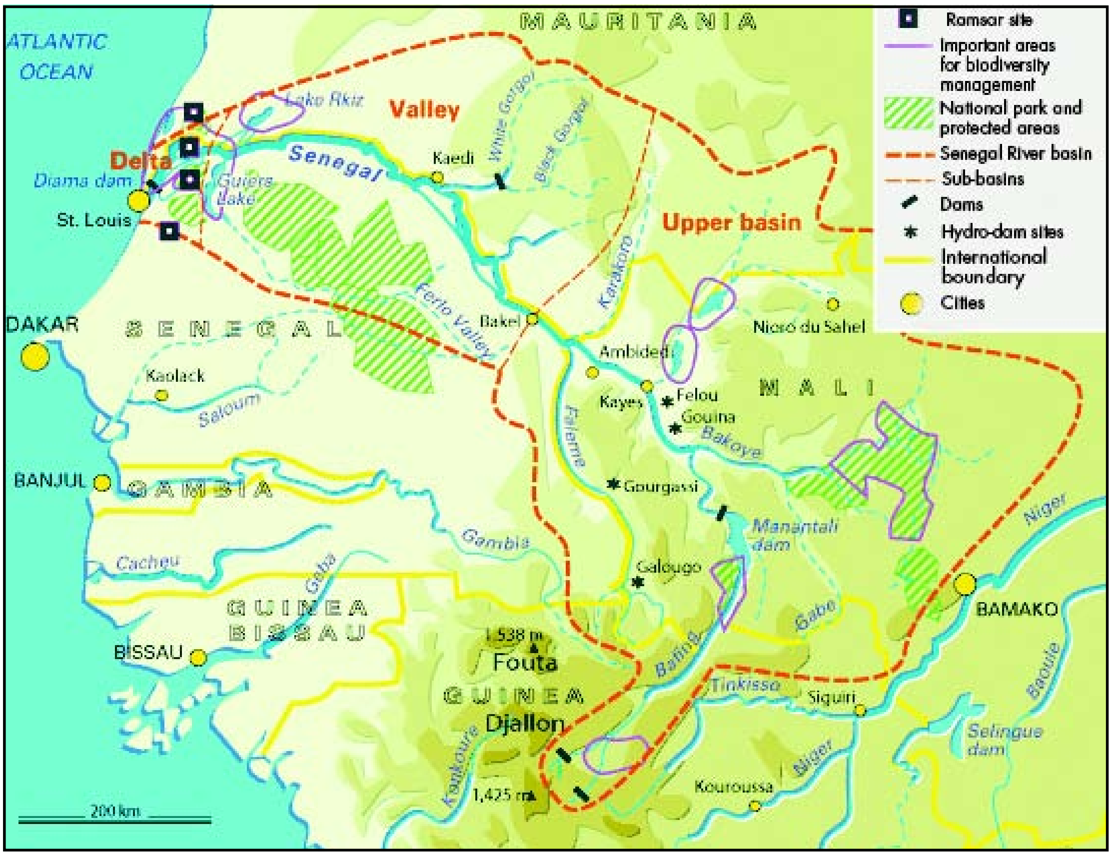

Figure 3.14: Senegal River Basin

Physiography
Like the rest of Western Africa, rainfall in the Senegal River Basin is influenced by the north-south migration of the Inter-Tropical Convergence Zone (ITCZ), and is characterised by inter-annual irregularity (coefficient of irregularity: k=1.5 to 2). A large north-south gradient is present, with the highest rainfall in the Fouta-Djalon area (up to 2,000 mm/year) and the lowest towards the north (less than 200 mm/year). Since the 1970s, the 400 mm isohyet shifted southward over a distance of ~100 km, thereby jeopardising rain-fed agriculture (see Figure 3.15). Evaporation ranges from 7-8 mm/day, whereas the annual average evaporation is ~3,000 mm. The degree of aridity, expressed as the ratio between annual precipitation and potential evapotranspiration, is shown in Table 3.7 for different periods at different basin locations. Aridity (arid: <0.25 and semi-arid: 0.25-0.45; Sehmi and Kunzewicz, 1997) was prevalent throughout the whole period between 1960 and 1996 and was highest (lowest ratio) in Podor in 1983.

The climate is characterised by one rainy season lasting 2-6 months and resulting in pronounced variations in stream flow. Since the early 1970s, the flow of the Senegal River has been affected by reduced rainfall and, in addition, by two dams constructed in the '80s, the Diama and the Manatali Dams.

Table 3.7: Aridity in the Senegal River Basin (Ecossen Project, 2000)

Location	1961-1970	1971-1980	1981-1990	1991-1996	1961-1996
Bakel	0.28	0.25	0.24	0.26	0.25
Matam	0.24	0.15	0.18	0.17	0.19
Podor	0.13	0.09	0.08	0.09	0.10

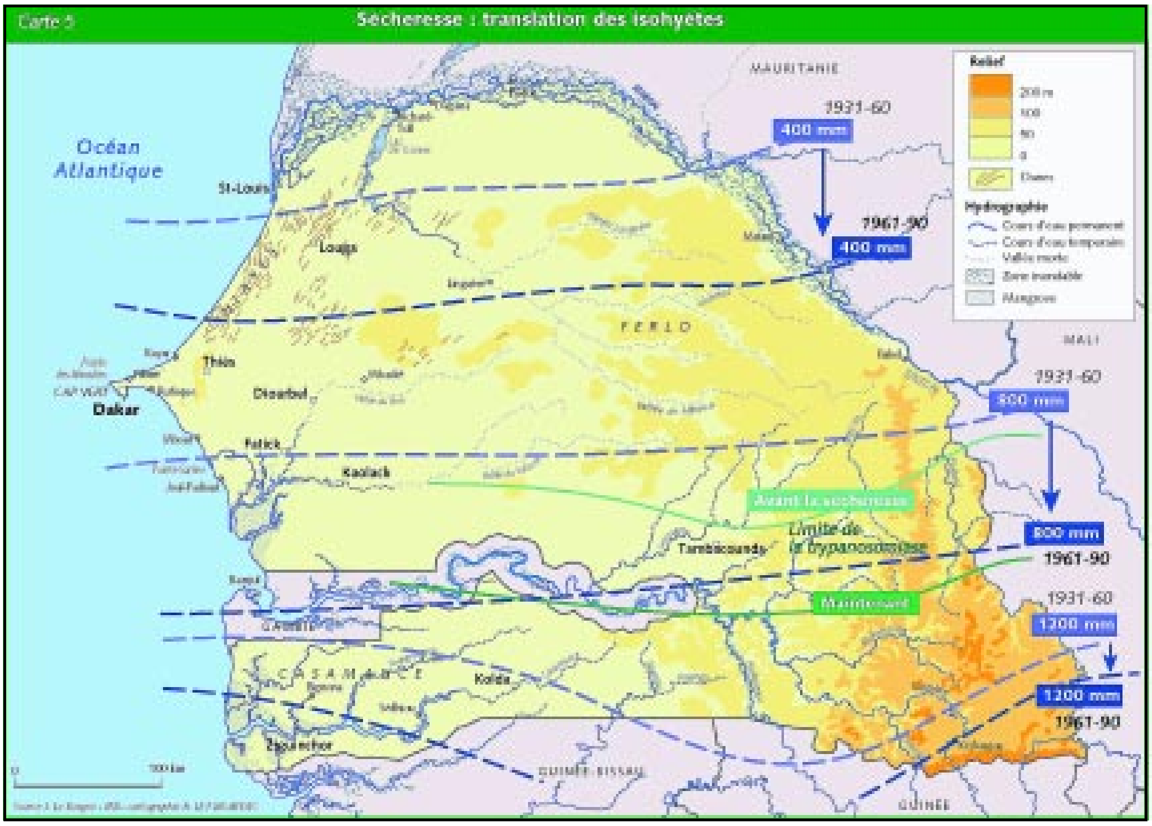

Figure 3.15: Southward shift of isohyets in the Senegal River Basin

Source: LeBorgne-IRD-Cartographie: www.bondy.ird.fr/carto/SenegalFIG/secheresse.html

Box 3.5: Senegal River Basin – Main characteristics

Basin:		**Water Use**
Surface area:	483,000 km^2	Agriculture
MAP:	550 mm/a	Domestic
		Hydropower
		↑ Increasing
Demography		
Population:	22 million	
Density:	40 persons/km^2	
Water Resources		**Major Dams**
River length:	1.800 km	Diama (limits seawater intrusion)
MAR:	21,800Mm^3/a	Manatali: 12,000 Mm^3
Major Acquifers		**Vulnerability**
Sedimentary		Increasing

The Diama Dam was built in the river delta to limit the intrusion of seawater during periods of low discharge and to protect the river ecosystem. The social, economic and environmental gains and losses associated with the dam are not well known. According to Gibb (1987), the total sediment transport over the period 1908-1934 in Bakel and in Saint-Louis was ~4 million tonnes. Only 30% of this quantity was deposited on the floodplains, whereas 70% reached the sea. Although time series of sediment transport are available for several stations in the basin, a wider range of factors need to be considered when assessing the impact of the dam.

The Manatali Dam on the Bafing tributary in Mali was built for hydroelectric power production and regulation of the river flow. The dam controls approximately 50% of the total flow. Ideally, operation of the dam should allow for both artificial flooding of the river valley (100,000 ha) and for secure navigation on the Senegal River. Inundations, however, have been much less effective than were planned for.

Plans for the future include the Fossil Valleys Project, which involves the building of a dam on the presently uncontrolled Faleme branch of the Senegal River and the diversion of river discharge into the dry valley system inside Senegal. This project is expected to have pronounced effects on both flood reduction and irrigated agriculture in the valley.

The Terminal Continental and Maestrichtian formations determine the availability of groundwater across the Senegal River Basin. Water quality of the aquifers in these formations varies laterally and with depth. In some places, concentrations of nitrates and phosphates exceed permissible limits. Gibb (1987) has already noted that water quality issues are not adequately addressed.

Vulnerability Indicators: Aridity and Water Availability

There has been a long-lasting drought in the Senegal River Basin for more than 30 years. The decrease in rainfall has led to a corresponding decrease in river flow, e.g. a 20% decrease in rainfall resulting in a 40% decrease in available water resources. The drought has reduced rain-fed agriculture, decreased the seasonal flooding of wetlands, limited economic development, and, overall, enhanced poverty. The key hydrological changes that have occurred in the basin are closely linked to the displacement of the isohyets to the south and the increase in evapotranspiration.

Socio-Economy

The socio-economic developments along the Senegal River mainly rely on the opportunities arising from the Manatali and Diama Dams (Table 3.8). The main focus within the basin is on agricultural activities. In the middle and lower valley, where the average rainfall is less than 300 mm per year, flood recession and irrigated (pump-based) agriculture dominate.

Table 3.8: Developments along the Senegal River

River / Site	Purpose	Date of construction	Capacity (Mm^3)
Bafing / Manatali	Hydropower (200 MW); Irrigation (300,000 ha); Navigation; Flood control	1987	12,000
Senegal / Diama	Control of saltwater intrusion; Water supply for Dakar	1986	-

Traditionally, flood recession has been the most important agricultural system and supports a relatively large population. The size of the inundated area and the duration of the inundation determine the potential for flood-recession agriculture in any given year. For a detailed account of the effects of river flow dynamics on flood-recession agriculture in the area, the reader is referred to Rasmussen et al (1999). The crops grown are mainly millet, sorghum and corn, and average yields are in the order of 400 kg/ha for cereal (Gibb, 1987). Crop production through pump-based irrigation has increased since the 1970s and is supported by national subsidies in Senegal. A Senegalese institution named Société Nationale d'Aménagement et d'Exploitation des Terres du Delta du Fleuve Sénégal (SAED) has been responsible for the establishment of irrigation schemes on the Senegalese side of the river. Here, rice is the main crop and yield levels are 1-6 ton/ha, with the higher yields only obtained in newly established or rehabilitated and well-functioning schemes. The importance of rain-fed agriculture is decreasing since the droughts of the 1970s, especially in the lower valley.

After the construction of the Manatali Dam, water availability was no longer the critical factor for irrigated agriculture in the region. Economic profitability, management difficulties and in particular the maintenance and replacement of pumps appeared to be the controlling factors. The construction of the Manatali Dam was also meant to generate hydroelectric power (800 GWh/year) and to secure adequate flow for navigation on the Senegal River all the way up to Kayes.

Vulnerability Indicators: Water Demand and Water Use for Food Production

For flood-recession agriculture, yields may be limited by water availability, plant nutrient availability, plant diseases, and/or attacks by insects or birds. The effect of limited water or nutrient availability is a low plant density.

Nutrient availability may have been influenced by changing patterns of inundation and the reduced deposition of mud on the floodplain following the construction of the Manatali Dam. The inundated area has been considerably reduced since the early 1970s and this, in combination with a considerable increase in the valley's population, has meant that the flood-recession agriculture can no longer ensure sustainable food production for the local market. Regarding irrigated agriculture, rice cultivation is based on large inputs of mineral fertilizers, and thus reductions in fertilizer input immediately lead to decreasing yields.

The study by Rasmussen et al (1999) has clearly demonstrated the importance of hydrological information for assessing agricultural development options in the Senegal River Valley. Peak flow of the river has a direct impact on the potential for flood-recession agriculture, whereas river discharge has a much smaller impact on irrigated agriculture. Economic and management factors appear to be more critical.

Management

Proper river basin management requires a hierarchy of institutions at different levels. In the case of the Senegal River Basin, these include institutions at the village, national and transboundary levels. The interests of institutions at different levels are likely to be in conflict (Rasmussen et al, 1999). The management of the water resources of the Senegal River has caused controversy between the countries involved and between the various stakeholder groups. Conflicts of interests have been associated with hydroelectric power production, allocation of and access to water for irrigation and domestic supplies, modern and traditional agricultural water requirements, and the conservation of wetland ecosystems and the wider environment.

To overcome these conflicting interests, a supra-national authority, Organisation pour la Mise en Valeur du Fleuve Sénégal (OMVS), was established to decide on water allocation and dam management principles within the river basin. Mali, Mauritania and Senegal are members of the OMVS, whereas Guinea, where most of the discharge originates, is not. The members have developed a legislative and institutional framework for the management of water resources in the basin. The institutional framework for each riparian country comprises:

- A representative of the OMVS;
- The ministry in charge of water resources;
- A national institution (e.g. SAED in Senegal);
- Institutions for water partnership (NGOs, donor agencies); and
- Associations (farmers, fishermen, women's associations, etc.).

In order to support decision-making, an appropriate hydrological model of the Senegal River Basin has been developed. It allows for analysis of the consequences of climate change and variability on the basin, of dam operations and land-use changes. It should, however, be emphasised that decision-making in water resources management, e.g. that associated with the operations of the Manatali and Diama Dams, as well as the planned future dam on the Faleme at Bakel, cannot be solely based on hydrological reasoning. Obviously, agronomic, economic, social and environmental issues also need to be taken into account.

3.3.2 Niger River Basin

The Niger River Basin covers 2.27 million km^2, with the active drainage area comprising less than 50% of the total. At 4,200 km in length, the Niger is the third longest river in Africa and the world's ninth largest river system (Figure 3.16). The basin is shared among 10 countries: Nigeria (27%), Mali (26%), Niger (24%), Algeria (8%), and Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire and Guinea (each <5%). The Niger River Basin is generally considered to be one of the two river basins (with the Volta) most affected by freshwater shortages. Box 3.6 summarises the main characteristics of the Niger Basin.

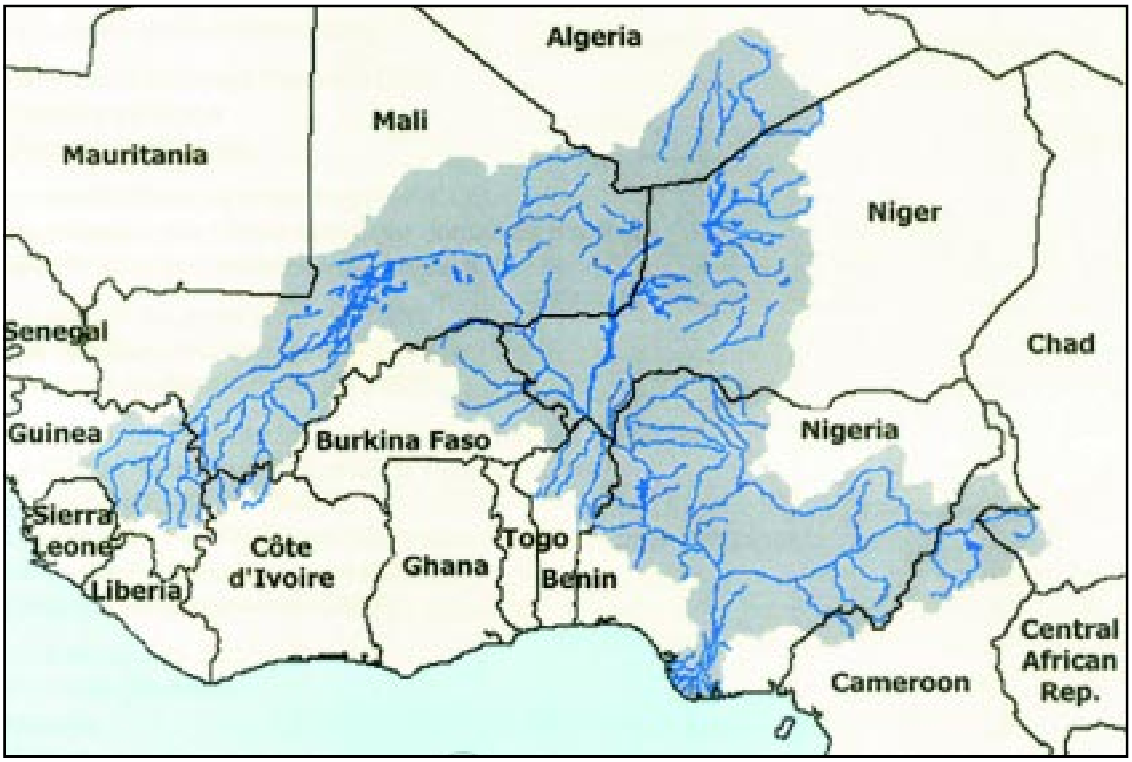

Figure 3.16: Niger River Basin

Physiography
For the past three decades, the Sahel area, in which the largest part of the Niger Basin is located, has experienced a persistent drought, resulting in a drastic decline in rainfall and a southward shift of rainfall zones by ~100 km.

The main environmental impacts resulting from the diminishing rainfall and related reduction in stream flows are:

- Reduced vegetation cover and changes in riparian habitats;
- Decreased wetlands areas; present coverage is 4.1% (IUCN-IWMI-Ramsar-WRI, 2003);
- Increased soil erosion and siltation;
- Water quality changes due to reduced dilution capacity;
- Deterioration of faunal habitats, depletion of fish stocks and reduction in species diversity.

Box 3.6: Niger River Basin – Main characteristics

Basin
Surface area: 2,270,000 km^2
MAP: 690 mm/a

Water Use (Increasing ↑)
Agriculture
Domestic
Hydropower

Demography
Population: 106 million
Density: 31 persons/km^2

Water Resources
River length: 4,200 km
MAR: 221,500 Mm^3/a

Major Dams
Dadin Kowa: 2,765 Mm^3
Selingue: 2,200 Mm^3
Kainji: 1,500 Mm^3
Goronyo: 1,100 Mm^3

Major Acquifers
Sedimentary and basement

Vulnerability
Increasing all over the basin

Based on hydrological and ecological diversity, the following four main sub-regions (or drainage areas) can be distinguished: Upper Niger, Inner Delta, Middle Niger and Lower Niger.

- The Upper Niger (upstream) extends over 140,000 km^2 from the source in Guinea to Ke-Macina in Mali. Its three main tributaries are the Tinkisso, Milo and Niandan Rivers. Before the river enters the Inner Delta in Mali, at the southern edge of the Sahara Desert, its flow averages 45 million km^3/year. The only significant control structure is the Selingue Dam on the Sankarani River, a tributary of the Niger. This single-purpose dam (hydropower) regulates approximately 5% of the upstream flows. A significant decrease in the intensity of high flows has been observed since the 1970s.
- The Inner Delta is a vast inland delta in Mali, covering an area of 80,000 km^2 from Ke-Macina to Timbuktu. It comprises complex and geographically extensive systems of rivers, lakes and floodplains that have undergone significant development. Some lakes (Debo and Horo) are classified as Ramsar protected sites and are important habitats of water-birds. The size of the delta is subject to seasonal and annual variations depending on inflows from the Upper Niger and Bani Rivers. The inundated area has decreased by 63% from 35,000 km^2 in 1967 to 9,500 km^2 in 1984. This area plays an important role in regulating the flow of the river. Only 50% of the average annual inflow of 70 billion m^3 reaches Timbuktu. The peak discharge of 6,000 m^3/s at Koulikoro (Upper Niger) in September has not only been reduced by 75% to 2,350 m^3/s, but has also been delayed by 2-3 months (December-January).
- The Middle Niger covers 900,000 km^2 in Mali, Niger and Benin. It is composed of a series of irrigated terraces. Upstream of the Niger Republic, the river receives inflow from the tributaries of Burkina Faso. Hydrologic monitoring, dating back to 1923, reveals that flows in the Middle Niger are significantly affected by flows from the Inner Delta. The mean annual flow at Niamey in 1971-2000 was a third less than the flows in 1929-70. This reduced flow has resulted in earlier and shorter floods.
- The Lower Niger at the downstream end is located in the humid zones of Nigeria. It has a catchment area of 450,000 km^2 and receives water from the major tributaries of Sokoto, Kaduna and Benue. Average runoff downstream of the Kainji and Jebba Dams is 1,454 m^3/s and 5,590 m^3/s after the confluence with the Benue River. Although the Benue contributes 50% of the Niger's flow, the hydrologic significance across the basin is low as it only flows through one country before joining the Niger River. Between 1929 and 1970, the annual average runoff was 6,055 m^3/s (almost 200 billion m^3/year), compared to 5,066 m^3/s (160 billion m≈ /year) from 1971 to 2001 – a reduction in runoff of almost 20%.

An overview of major developments in the Niger River Basin in terms of hydropower generation and irrigation is presented in Table 3.9.

The basin has experienced a continued reduction in renewable water resources due to both natural (drought) and human-induced changes. The latter include overexploitation of water resources (including inefficient water storage in large reservoirs with high evaporative losses and over-abstraction of groundwater resources) and land-use changes (including deforestation). The predominance of dry years with persistent droughts over the past three decades has led to:

- A decrease of about 40% of average annual flows of the Niger River between 1907-73 and 1974-94 (NBA-HydroNiger);
- A decrease in groundwater levels in the alluvial aquifers, resulting in lower base flows, reduced groundwater recharge, and decreasing aquifer storage;
- A reduction of the river's sediment transport capability, degradation and erosion of slopes and riverbanks, and increased siltation. This situation has been further aggravated by increasing pressure from people and animals.

A major issue in the coastal area is the modification of stream flows – an increase or decrease in the discharge of streams and rivers – as a result of human interventions on a local or regional scale. Modification of stream flows, for example through damming, has changed the occurrence of exceptional discharges, and, to a lesser extent, has changed the inter-annual salinity of estuaries or coastal lagoons and/or the position of the estuarine mixing zone.

While Nigeria benefits from being a major oil-producing nation, with an average crude-oil production of 2 million barrels per day, a major issue of concern is the environmental damage caused by frequent oil spills during the production and distribution processes. Between 1976 and 1998, 5,724 spillage incidents led to 2.57 million barrels of oil being spilled in the Niger Delta (Nwilo and Badejo, 2003). The spills caused the destruction of aquatic life and biodiversity, the degradation of fertile soil, and the pollution of drinking water, as well as political unrest.

Table 3.9: Major developments in the Niger River Basin (after Mott MacDonald, 1992)

Development	River	Country	Type	Remarks
Selingue Dam	Sankarani	Mali	Multi-purpose	2,000 ha irrigation / 44 MW hydropower
Markala Lagdo Dam	Benue	Cameroon	Irrigation	60,000 ha
Goronyo	Sokoto	Nigeria	Irrigation	33,000 ha
Bakolori Dam	Sokoto	Nigeria	Irrigation	450 million m^3 reservoir
Kainji	Niger	Nigeria	Hydropower	760 MW
Jebba	Niger	Nigeria	Hydropower	500 MW
Shiroro	Chanchanga	Nigeria	Hydropower	300 MW
Kiri	Gongola	Nigeria	Irrigation	325 million m^3 reservoir
Dadin Kowa	Gongola	Nigeria	Irrigation	2,765 million m^3 reservoir
Tungan Kawo	Niger	Nigeria	Irrigation	22 million m^3 reservoir / 800 ha
Under construction: Omi	Kampe	Nigeria	Irrigation	6,000 ha
Under Investigation:				
Fomi	Niandan	Guinea	Multi-purpose	Hydropower
Tossaye	Niger	Niger / Mali / Burkina Faso	Multi-purpose	83,000 ha irrigation, >2.5 km^3 reservoir, 30-40 MW
Kandaji	Niger	Niger	Multi-purpose	Irrigation / hydropower
Zunguru	Kaduna	Nigeria	Hydropower	950 MW
Makurdi	Benue	Nigeria	Hydropower	600 MW
Lokoja	Niger	Nigeria	Hydropower	1,950 MW
Onitsha	Niger	Nigeria	Hydropower	750 MW

Socio-Economy

The total population of the Niger River Basin was over 106 million in 2000, with an average density of 31 people/km^2 (IUCN-IWMI-Ramsar-WRI, 2003). The degree of urbanisation in Western Africa is expected to reach 65% by 2025, and individuals living in rural areas will have to produce enough food to meet their own needs as well as those of the growing urban population. Crop yields will thus have to increase through intensified farming and the expansion of irrigated areas – both of which will place further pressure on freshwater resources. The Global Water Partnership (2000) estimates that, by 2025, per capita water consumption will be 100 litres per day in cities and 50 litres per day in rural areas.

From a socio-economic point of view, the combined effects of increased water shortages, water stress and urbanisation are expected to result in:

- Reduction in future land-use options (loss of land for agriculture) and reduced agricultural productivity;
- Loss of hydroelectric power production and increased costs of alternative water supplies;
- Increased losses relating to water supply and consequently greater health risks;
- Increased costs for the protection of health of human and animal populations.

Freshwater shortages have also begun to trigger major human migrations, with far-reaching transboundary implications. Future freshwater shortages may also trigger upstream-downstream water-related conflicts between different user groups.

Management

The Niger River Basin, when compared with the Senegal River Basin, has a poor legal framework at both the regional and national levels. It is also characterised by inadequate implementation of available regulatory instruments. As is the case for the Senegal River Basin, a supra-national institution named Autorité du Bassin du Fleuve Niger (ABN) has been created by the riparian countries. In each country the institutional framework for the water sector is created by the ministry in charge of water resources. There is also a pressing need for the modification of environmental laws and regulations in Nigeria to address oil spillage problems in the Niger Delta in line with the polluter-pays principle.

3.3.3 Comparison of Senegal and Niger River Basins

A brief summary of the main aspects of water resource vulnerability in the Senegal and Niger River Basins is presented in Table 3.10.

Table 3.10: Water resource vulnerability in the Senegal and Niger River Basins

Cluster	Vulnerability Indicator*	Senegal River Basin	Niger River Basin
Physiography	Aridity	>75% arid and semi-arid	50% arid and 50% semi-arid
	Water availability infrastructure	Stressed	Stressed
	Storage and supply infrastructure	Underdeveloped throughout the basin	Developed down-stream (Nigeria)
Socio- Economy	Population density	40 persons/km^2	31 persons/km^2
	Access to safe water	Variable	Variable
	Water use	>60% for agriculture	50% for agriculture
	Poverty	High	High
	Conflicts	Moderate	No conflict
Management	Sector reform	In progress	Delayed
	Implementation and adaptive capacity	Moderate	Very low
	Data availability, gaps and quality	Moderate (CILSS, OMVS)	Moderate (CILSS, NBA)

Physiography

- Over 75% of the area of the Senegal River Basin can be classified as arid to semi-arid, with Mauritania having the highest aridity (~50% of the total basin area). The Niger River Basin has been particularly affected by the long-lasting drought in the Sahel. The Niger River dried up in Malanville (Benin) in 1985, making water availability critical for riparian countries.
- The main impacts of environmental change on water resources in Western Africa are related to changes in stream flow, the pollution of existing supplies, and changes in the water table. Climate change and variability predictions suggest an aggravation of the situation, with a decrease in rainfall, runoff and recharge, especially in large parts of the Niger River Basin.
- Most of the riparian countries of the Senegal and Niger Rivers that are vulnerable to changes in rainfall and stream flow are members of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS). Through this committee an effort is being made to cope with climate change and variability.

Socio-Economy

- One of the common characteristics of the Senegal and Niger River Basins is the high proportion of the population under 15 years old. The combined effect of a growing (urban) population while water supply structures are still underdeveloped will put further pressure on the provision of safe drinking water and sanitation, especially in the urban areas. In most urban areas, access to water is hardly more than 50 litres per capita/day, whereas in rural areas this is generally less than 20 litres per capita/day.
- The relatively low GDP of all the riparian states in the two river basins confirms that poverty is prevalent in both. The socio-economic situation of the region may further deteriorate with the expected climate change and variability in Western Africa.
- Agricultural water use dominates in most West African countries compared to domestic and industrial uses. Agriculture accounts for over 60% of freshwater use in the Senegal River Basin and over 50% in the Niger River Basin.
- Water-related conflicts among different stakeholders (local, national and transboundary) may constitute a constraint to development in the Senegal River Basin because of the demands and pressures that continue to be placed on the limited water resources. The Fossil Valley Project aims at developing the agricultural potential of a dry-valley system in the northern and central part of Senegal by diverting water from a tributary of the Senegal River to the central part of the country where there is no active river channel.

Management

- The institutional framework and water-related legislation and guidelines are relatively well-developed for the Senegal River Basin, whereas institutional and legislative frameworks for the Niger Basin are presently very weak. Progress is being made by the Niger River Basin Authority (NBA) to promote appropriate water-related legislation and to establish new institutions for the management of the basin's water resources. It should be noted that the OMVS of the Senegal River Basin uses hydrological models for the general purpose of water resources management, while in the Niger Basin hydrological models are mainly used for flood forecasting.
- Regarding data availability and knowledge gaps, a great number of initiatives have been carried out or are underway at the regional level. Probably the most significant of these was the establishment of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) in 1974. So far, the CILSS has carried out the following broad range of activities: (a) collection and management of data on climate, hydrology, soils, and socio-economic aspects; (b) dissemination of climatic information to member states and other target groups; (c) establishment of an early warning system based on weather data, agro-ecosystem models and geographical information systems; and (d) research and training through its AGRHYMET Regional Centre. Other important initiatives are AGRHYMET's Regional Centre project 'Strengthening the Capacities of the CILSS Member States to Adapt to Climate Change in the Sahel' and NBA's and AGRHYMET's pilot phase of HYCOS-AOC, the West and Central Africa Component of the World Hydrological Cycle Observing System (WHYCOS) of WMO (WMO/MAE, 1997). More information of a better quality and greater detail is thus being collected across the region. It should be noted that less attention is being paid to data collection of groundwater resources than to surface water resources even though most of the rural communities in both river basins rely on groundwater for their domestic water requirements.

Water Scarcity

- Although the coastal region of Western Africa is often considered to be endowed with larger water resources than the Sahelian region, development in both regions is constrained by water scarcity. By the year 2025, most of the Western African countries will be under water stress. Studies are underway to assess the impacts of climate change and variability on water supply, land use, land degradation and food production (CILSS). Within the framework of this project and in close cooperation with local communities, an inventory and evaluation of indigenous knowledge with respect to adaptation to climate variability is foreseen.

3.4 Northern Africa

One of Africa's most peculiar regions where arid climatic conditions express the main physical constraints on water availability is the Northern African region (Figure 3.17). Desert conditions prevail throughout the region, except for the narrow coastal strip along the Mediterranean shoreline. The harsh conditions in the Sahara Desert have compelled approximately 70-90% of the populations of most of the Northern African countries to live along the Mediterranean coast and the Nile River.

There are few river and groundwater basins in Northern Africa. Of these, the Nile River Basin is the most important. The Nile River, which is the longest river in the world and crosses various climatic zones, is the major water supply for one of the most arid zones in Africa. The river basin is inhabited by more than 160 million people in 10 countries: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda.

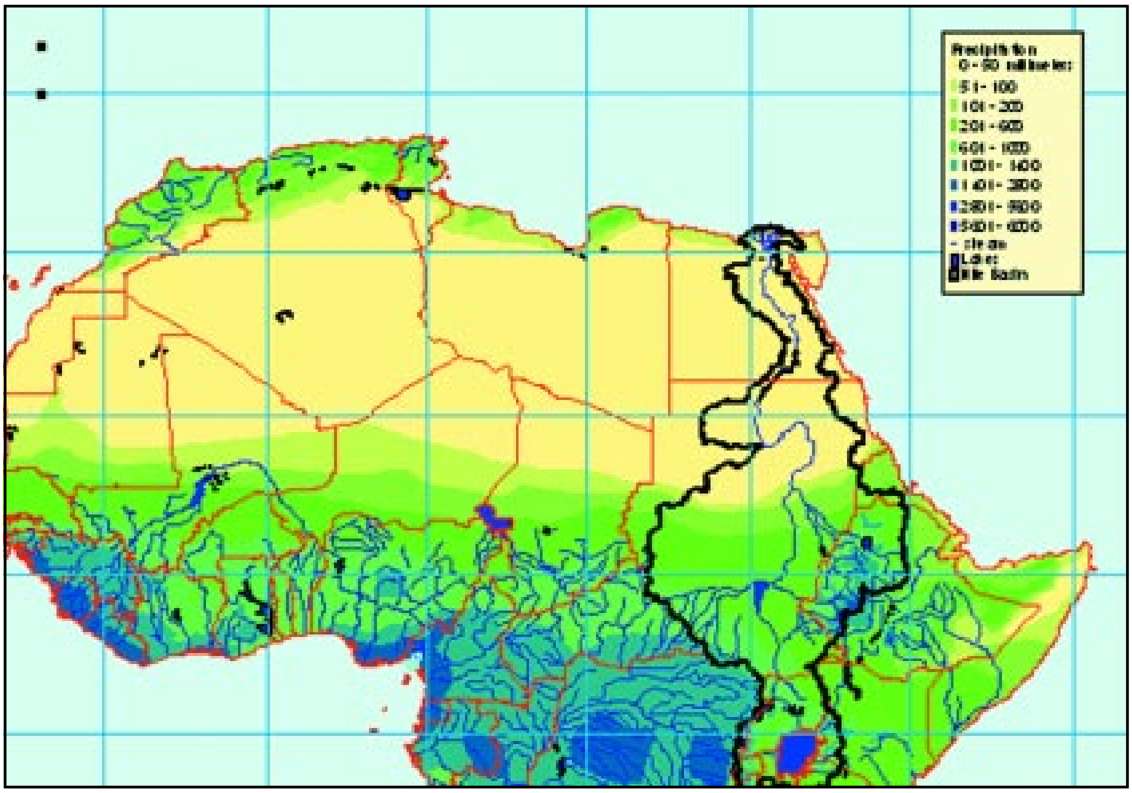

Figure 3.17: Northern Africa – Rainfall, rivers and the Nile River Basin

Source: Rainfall: ESRI. 1998; Rivers and Dams: ESRI, 1992

Physiography

The Northern African region includes Egypt, Libya and the Maghreb countries – Morocco, Tunisia and Algeria – and covers a total area of about 6.5 million km^2. Algeria is the largest of these countries, occupying a surface area of 2.4 million km^2. Although Sudan and Mauritania are not included in the Northern African region, in various other regional groupings of countries they are considered part of this region (CEDARE/GWP-Med, 2002).

The region lies in the arid to semi-arid climatic zones, where dry conditions prevail, except for a narrow strip in the northern parts along the Mediterranean Sea. Annual rainfall is highest along the north coast and decreases southwards. It ranges from less than 50 mm in the southern parts (deserts) to 1,000 mm in some parts of the extreme northwest.

The land cover in Northern Africa largely mirrors its climate, with more than 90% characterised by desert and semi-desert vegetation (Figure 3.18).

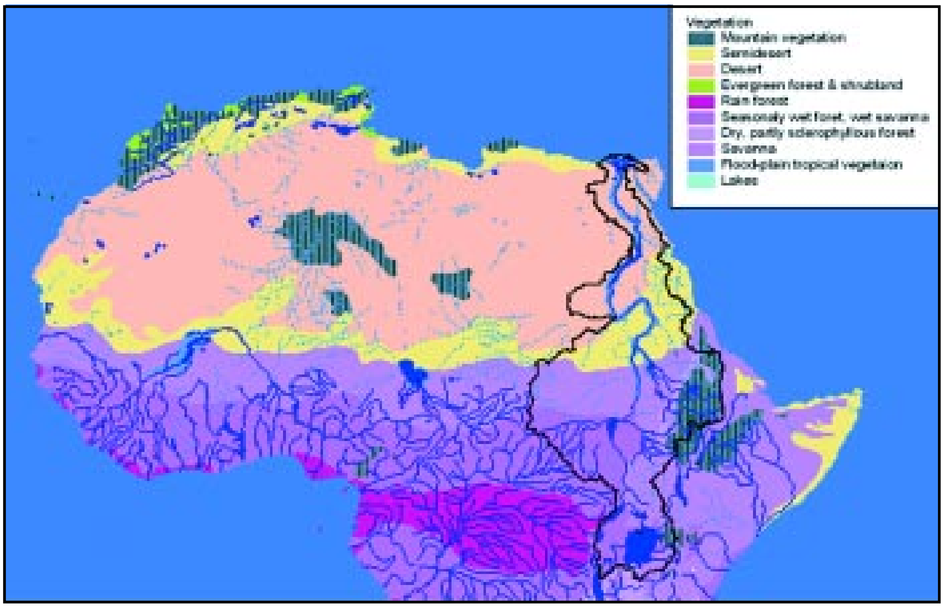

Figure 3.18: Northern Africa land cover

Source: ArcAtlas, ESRI

Groundwater plays a vital role in fulfilling basic water requirements in many parts of Northern Africa, but the aquifers are mostly non-renewable and transboundary by nature. There are two major shared aquifer systems in Northern Africa, namely the Nubian Sandstone Aquifer System (NSAS) and the North Western Sahara Aquifer System (NWSAS). The Nubian Sandstone Aquifer System is located in the northeast of Africa and is shared by Egypt, Libya, Sudan and Chad. Libya, Tunisia and Algeria share the North Western Sahara Aquifer System.

Vulnerability Indicators: Aridity and Water Availability

Due to the high aridity and recurrent droughts, the region's water resources are highly vulnerable. The average annual renewable water resources in Northern Africa (as per 2000) total about 950 m^3/capita/year, which is below the 1,000 m^3/capita/year threshold of water scarcity.

Socio-Economy

The combined population of Algeria, Morocco, Tunisia, Libya and Egypt increased from less than 128 million in 1994 to nearly 135 million in 2000, which translates to an average annual growth rate of about 1% (Figure 3.19). Figure 3.19: Present and projected population growth in Northern Africa (WRI, 2002)

The population increase was accompanied by a rapid growth of large cities and rural population concentrations, putting intense pressure on infrastructures that are barely capable of meeting citizens' basic requirements, particularly in the areas of drinking water, sewerage, and waste management services.

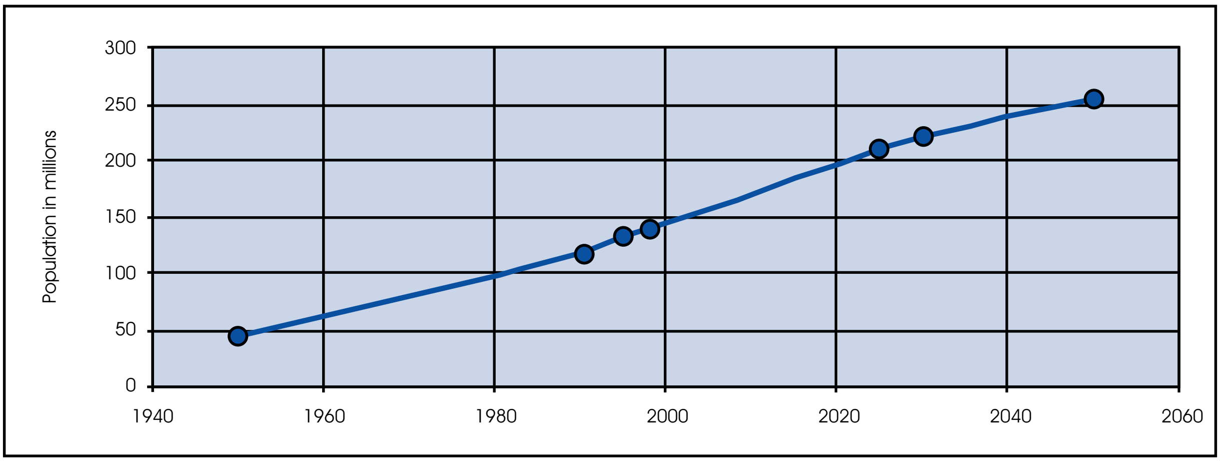

Figure 3.19: Present and projected population growth in Northern Africa (WRI, 2002)

Vulnerability Indicators: Water Demand and Water Use

The challenge of meeting Northern Africa's water demands is mainly determined by the limited amount of renewable water resources. At present, available water resources are insufficient and future projections of increasing water demand and water use are expected to further aggravate an already precarious situation.

The majority of the Northern African countries suffer from a substantial lack of rainfall and surface water resources and therefore are heavily reliant on their groundwater resources, which in some cases are non-renewable. The utilisation of non-renewable groundwater and protection of groundwater quality for sustaining future generations has become a complex issue, particularly with regard to the question of sustainability. In a number of cases there appears to be no choice other than to rationalise the use of water resources, increase recycling and reuse, and prevent water pollution.

Vulnerability Indicator: Population Density and Growth

The main population centres in Northern Africa are concentrated along the north coast and along the Nile River, with annual population growth rates varying between 1.8 and 3%. Increased water demand and the potential for pollution hazards illustrate the human-induced stresses on water resources associated with these population centres.

Vulnerability Indicator: Water-Related Conflicts

The average per capita renewable water resources in Northern Africa have dropped from 3,430 m^3 in 1960 to less than 1,000 m^3 in 2000, and are expected to further fall to 667 m^3 by 2025. In several countries, renewable fresh water will thus barely meet basic human needs in about 20 years. This will likely increase competition for water resources between different water-use sectors within the countries. Water-related conflicts may also arise due to increased competition between riparian countries over shared and non-renewable water resources, especially in the absence of a comprehensive assessment of the true potential of available water resources in many of these shared water basins.

Management

Participatory approaches are increasingly being introduced at various levels in water resources management. Examples are the establishment of Water Use Associations in Egypt and the National Water Council in Morocco. It will remain essential, however, that national policies, strategies and legal frameworks are harmonised and centrally coordinated. With increasing competition among water users, the implementing institutions will have to find a balance between diverse water requirements on the one hand and the availability of water resources on the other.

Vulnerability Indicator: Sector Reform

Since the 1990s, most countries in the region have acknowledged that the 'business as usual' scenario for dealing with water management and water security issues is no longer suitable to cope with future challenges. A gradual shift to Integrated Water Resources Management is being initiated throughout the region with variable levels of implementation. There is an actual need for the development of institutional frameworks for strengthening national and local institutions in the water sector, for better management of shared river basins and aquifers, for building the institutional capacities for the implementation of IWRM, and for good water governance.

Vulnerability Studies in Northern Africa

Few vulnerability studies have addressed the vulnerability of water resources to climate change and to human-induced effects. Studies on the vulnerability of water resources to climate change in Northern Africa include:

- Vulnerability of Northern African Countries to Climatic Changes: http://www.cckn.net/compendium/north_africa.asp;
- *Water and Climatic Changes in North Africa,* a book published in 1998 within the framework of the UNEP-GEF Project RAB94G31;
- *Climate and Health in North Africa,* a book published in 2002 within the framework of the UNEP-GEF Project RAB94G31.

3.4.1 Nile River Basin

The Nile River Basin covers a large area of ~3 million km^2, approximately 10% of the African continent, and contains the longest river in the world, with a total length of approximately 6,700 km (Figure 3.20;

Box 3.7). The basin is shared among 10 countries and extends from latitude 4° S to 31° N and from longitude 21° E to 40° E. Because of its size and variety of climates and topographies, it is one of the most complex major river basins in the world.

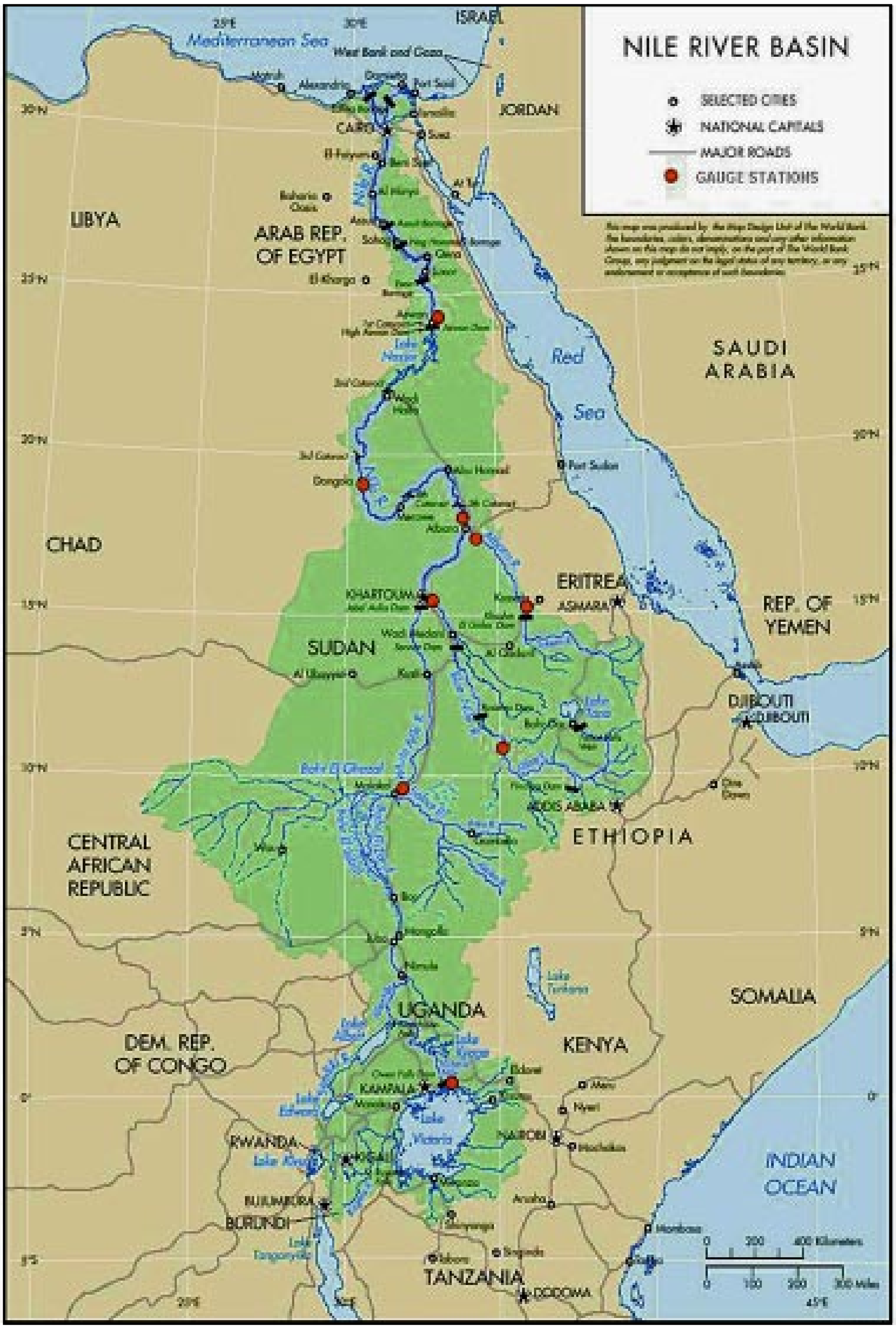

Figure 3.20: Nile River Basin (World Bank, 2001)

The Nile has three sources: the basin of the Equatorial Lakes plateau, the Ethiopian highland plateau, and the Bahr el Ghazal Basin. Almost 85% of the annual flow at Aswan in Egypt originates from precipitation on the Ethiopian Highlands through the Sobat, Blue Nile and Atbara Rivers. The remaining 15% originates from the Equatorial Lakes through the White Nile. The Lake Victoria Basin, the major sub-basin of the Equatorial Lakes and the Nile River Basin, was described in detail in the Eastern Africa Section (Sub-Section 3.2.1).

Box 3.7: Nile River Basin – Main characteristics

Basin	
Surface area:	2,900,000 km^2
MAP:	0 - 2,100 mm/a
Demography	
Population:	160 million
Density:	55 persons/km^2
Water Resources	
River length:	6,700 km
Rainfall:	1,660,000 Mm^3/a
River Flow:	55,500 Mm^3/a (at Aswan)
Major Dams	
Owen Falls Dam:	2,750,000 Mm^3/a (350 MW)
High Aswan:	162,000 Mm^3/a (2100 MW)
Aswan Dam:	5,000 Mm^3/a (345 MW)
Roseires:	3,000 Mm^3/a (210 MW)
Gebel Aulia:	2,500 Mm^3/a
Khashm Elgirba:	1,300 Mm^3/a (13 MW)
Sennar Dam:	930 Mm^3/a (15 MW)
Total dam storage:	2,924,730 Mm^3
Major Acquifer	
Nubian Sandstone	

Water Use (Increasing ↑)
Agriculture
Domestic
Industry
Mining
Hydropower

Vulnerability
Increasing to the north

Source: World Resources Institute (WRI, 2002); Nile Water Sector, Egypt

Physiography

Rainfall in the Nile River Basin ranges from basically nil in most of Egypt and northern Sudan, to almost 2,100 mm/annum on the Equatorial Lakes and the Ethiopian Highlands. The average total rainfall volume over the Nile River Basin is ~1,660,000 million m^3/annum. Less than 4% (55,500 Mm^3/a) of this amount reaches Northern Africa through the Nile at the High Aswan Dam in Egypt, where it is fully utilised within the country before the river flows into the Mediterranean Sea. The average annual discharge of the Nile upstream of Egypt (84,000 Mm^3/a) is less than 6% of the average total rainfall over the basin. The remaining 94% is kept upstream, where it is either used, lost to groundwater seepage or evaporation, or stored in surface water bodies.

Cropland coverage within the Nile basin varies significantly between countries, ranging from about 47% in Burundi and Rwanda to just 3% in Egypt. The same holds true for coverages of pastureland: 0% in Egypt, but up to 30% in Burundi and Rwanda. As for forest and woodland coverage, Egypt has the lowest while the Democratic Republic of Congo has the highest, at nearly 75% of its total land area.

Groundwater resources within the Nile River Basin are highly variable, both in terms of their renewability and their extent. In the north of the basin, the main aquifers are the Nile Valley System and the Nubian Sandstone Aquifer System. The Nubian Sandstone Aquifer is fossil, i.e. non-renewable.

The per capita annual 'potential renewable water resources' (PRWR) and 'forests, vegetation and cultivated land' for each of the riparian countries is given in Figure 3.22. The data clearly demonstrate the decreasing availability of renewable water resources, forests and cultivated land from south to north, and thus an increasing vulnerability in the same direction.

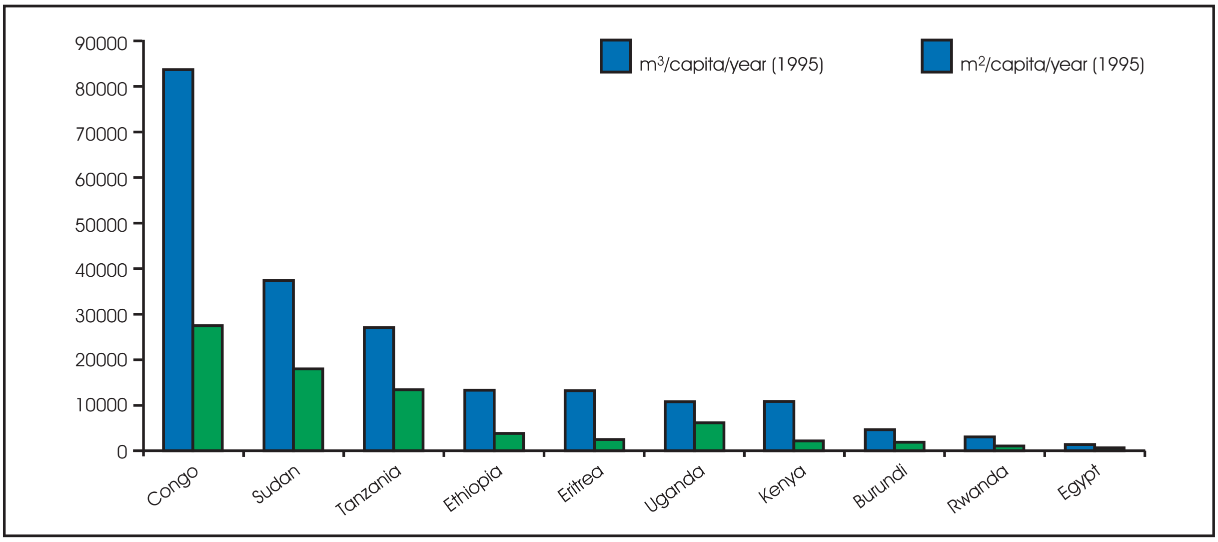

Figure 3.21: Per capita potential renewable water resources (m^3/capita/year) and forests, vegetation and cultivated land (m^2/capita/year) (Abu-Zeid, 1996)

It should be noted that the above data are preliminary estimates and that further investigations and detailed assessments are required for verification, particularly with regard to the groundwater resources in the Nile basin.

Vulnerability Indicator: Climate Change

The impact of climate change and/or variability on the water resources of the Nile River Basin is illustrated in Figure 3.22. A stream hydrograph is shown for one of the gauging stations along the Nile River, the Atbara Station, which was established early in the 20th century. The hydrograph covers a 90-year period of monitoring from 1907 to 1997. Three distinct periods of water-level rise and decline can be seen from the graph: the first period from 1907 to 1961 with a slightly rising water level, the second from 1962 to 1984 with a steep decline, and the third from 1987 to 1997 with a water-level rise as steep as the decline in the previous period.

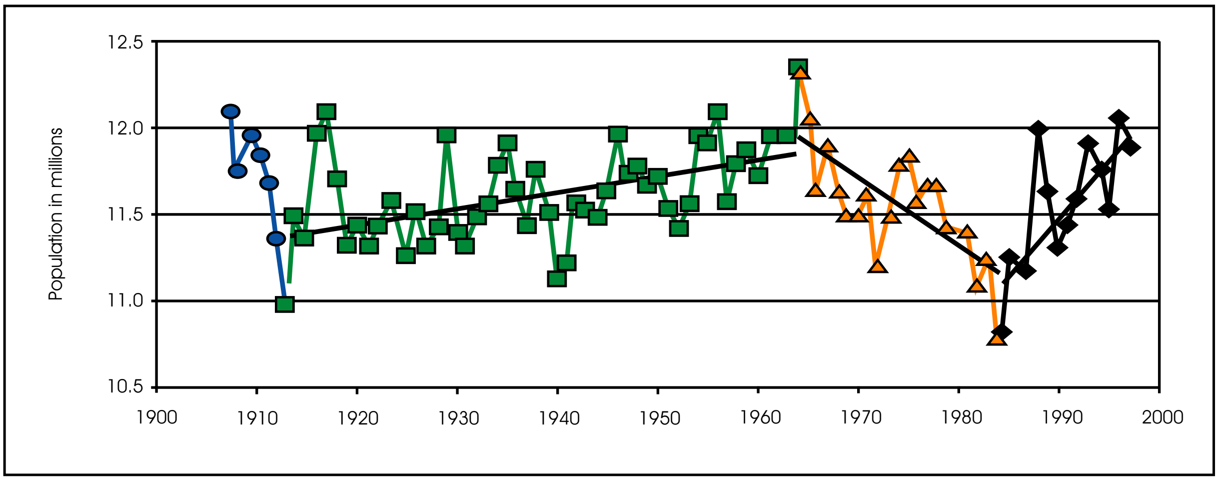

Figure 3.22: Annual average stream levels on the Nile at Atbara (Nile Water Sector, 2003)

Socio-Economy

Population figures for 1997 (WRI, 2002) show that there were just over 160 million people living in the Nile River Basin, which translates to an average population density of about 55 persons/km^2.

Agriculture is the main economic activity in most of the Nile basin countries. It contributes 35-50% to the overall GDP and provides employment to 60-90% of the workforce. Only Egypt has a smaller agricultural sector, contributing 17% of the country's GDP and providing employment to about 30% of the population.

Vulnerability Indicators: Population Growth and Urbanisation
Population growth and urbanisation in the Nile River Basin countries increase wastewater disposal, which most likely results in a deterioration of the river water quality. Upstream pollution will also affect downstream water quality. Increased urbanisation in upstream countries may also result in increased flooding in downstream countries since urbanisation decreases soil infiltration and natural evapotranspiration and more runoff will contribute to river flows to downstream countries.

Vulnerability Indicator: Water-Related Conflicts
The Nile River Basin is shared by 10 countries with varying dependencies on and needs for fresh water. While the upstream countries depend more directly on the rain that falls over the basin to sustain their forests, wildlife, lake ecosystems, rain-fed agriculture, fishing and groundwater recharge, for the downstream countries the Nile River is the only renewable water resource they have to sustain irrigated agriculture and drinking water supplies.

There is enough water in the Nile River Basin to sustain its population. If rainfall were evenly distributed over the basin, the per capita water share of the basin population would be more than 10,000 m^3/capita/year – or 10 times the water scarcity limit of 1,000 m^3/capita/year. However, the per capita water share downstream is less than 1,000 m^3/capita/year. Water problems upstream are more related to drainage, flood protection, occasional droughts and drinking water infrastructure, while water problems downstream are more related to water scarcity. Once these problems are clearly identified and understood, there could be a great potential for transboundary cooperation instead of conflict. Upstream countries could use surface waterways to generate power for groundwater development in remote areas, in order to supply drinking water and supplement irrigation in periods of drought. Meanwhile, projects for decreasing evaporation losses and preventing flood hazards upstream could be developed to make additional river flows available for the countries downstream.

Thinking along these lines, negotiations recently started between the Nile River Basin countries under the Nile Basin Initiative (see following section). This is expected to result in joint projects and possibly a treaty representing a common understanding among the basin countries.

Management
The sharing and utilisation of the Nile waters has long been governed by colonial treaties (1929: Egypt and Britain; 1959: Egypt and Sudan). Since 1967, a number of basin countries have been collaborating on technical issues. The first regional Nile River Basin project was the Hydromet (Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Albert). This involved Burundi, Egypt, Kenya, Rwanda, Sudan, Tanzania, Uganda and Zaire, with Ethiopia participating as an observer.

In 1992, the Ministers of Water Affairs of six of the Nile River Basin countries established the Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile River Basin (TECCONILE). The TECCONILE members were Egypt, Kenya, Rwanda, Sudan, Tanzania, Uganda and Zaire. Burundi, Ethiopia and Kenya participated as observers.

In February 1999, the Nile Basin Initiative was launched. The Initiative is a regional partnership through which the 10 basin countries have united in common pursuit of the long-term development and management of the Nile's waters. The Initiative is developing an agreed basin-wide framework and is guided by a shared vision "to achieve sustainable socio-economic development through the equitable utilisation of, and benefit from, the common Nile Basin water resources." The 10 basin countries have now at least started to speak openly about the challenges they face.

3.4.2 Nubian Sandstone Aquifer System

The Nubian Sandstone Aquifer System (NSAS) is a large fossil groundwater basin (Figure 3.23), which is considered to be one of the most important aquifers in the world. The NSAS extends across the borders of four African countries, namely Egypt, Libya, Sudan and Chad. It covers a total area of 2,200,000 km^2 and encompasses the major part of Egypt (37%), the eastern part of Libya (35%), the northwestern part of Sudan (17%), and the extreme northeast of Chad (11%). Thick layers of highly porous continental sediments form an enormous water storage system. The main characteristics of the NSAS are presented in Box 3.8.

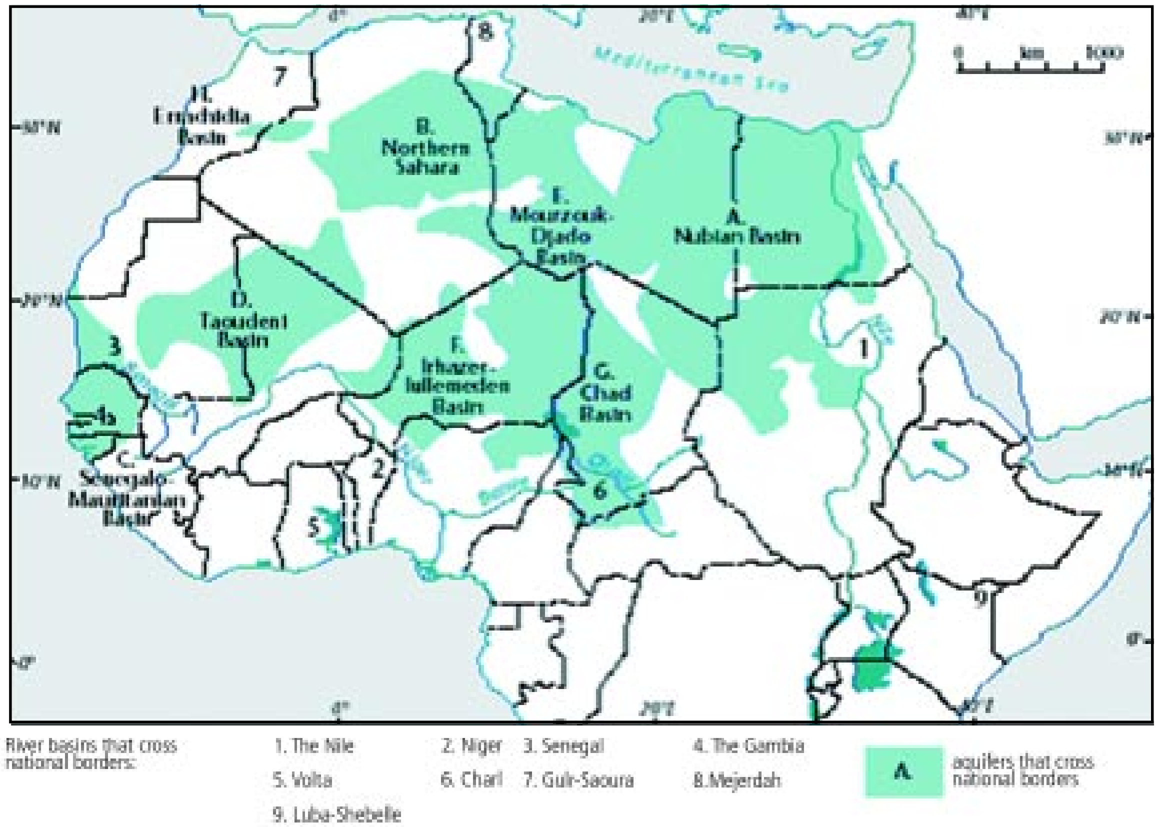

Figure 3.23: Internationally shared aquifers in Northern Africa (UNESCO, 2001)

The regional geologic structure of the NSAS was established in late Paleozoic times and sedimentation continued into the Tertiary period (CEDARE, 2001). To the south and west, the borders are formed by the basement outcrops of the Kordofan block, the Tibesti Mountains and the eastern slopes of Jabal Haruj (Figure 3.24). To the north, the border is formed by the Mediterranean Sea, while to the east, the borders are formed by the basement outcrops of the Nubian plate. The crystalline basement complex is considered impervious.

Box 3.8: Nubian Sandstone Aquifer System – Main characteristics

Basin:
Surface area: 2,200,000 km^2

Water Use (Increasing ↑)
Agriculture
Domestic
Mining
Industry

Demography
Population: 0.76 million
Density: 0.3 persons/km^2

Major Acquifer
Nubian Sub-System
Unconfined recoveratble volume: 8,800 km^3
Confined recoveratble volume: 9 km^3
Post-Nubian Sub-System
Unconfined recoveratble volume: 6,000 km^2

Vulnerability
Increasing aridity to the north

Source: CEDARE, 2001; Abu-Zeid, 2004

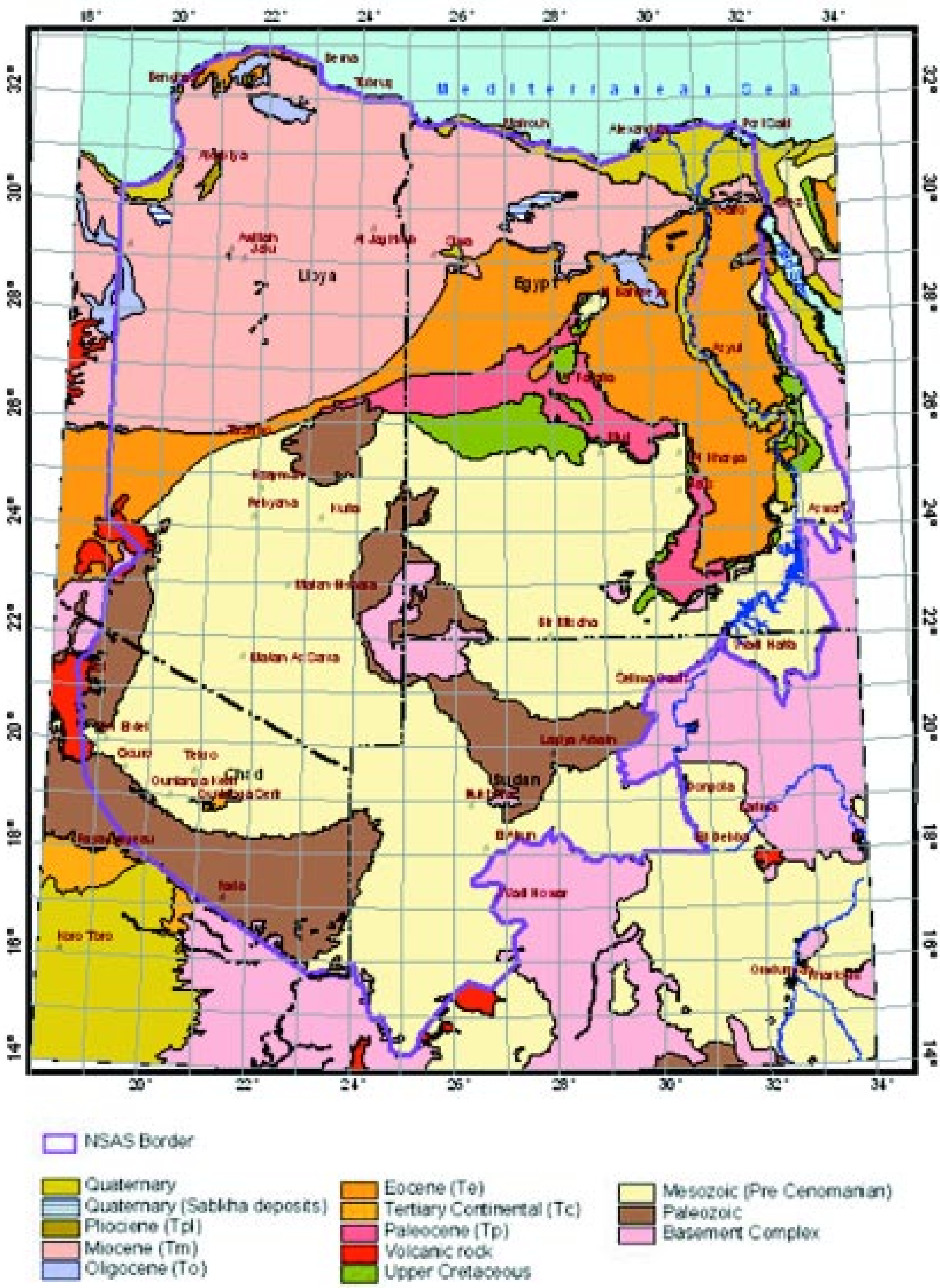

Figure 3.24: Nubian Sandstone Aquifer System (CEDARE, 2001)

Physiography

The Nubian Sandstone Aquifer System occurs mainly in the Arid Zone Belt of Northern Africa, where the average annual rainfall is very low: it rarely exceeds 25 mm/yr (Figure 3.25. In the northern part of the area, Mediterranean temperate climatic conditions prevail, with annual rainfall slightly exceeding 100 mm. Tropical rains occur locally in the southern part of the area, with annual rainfall reaching 1,000 mm. Rainfall amounts within the NSAS and adjacent areas have not changed over the past 120 years; it is generally erratic and shows periodicity.

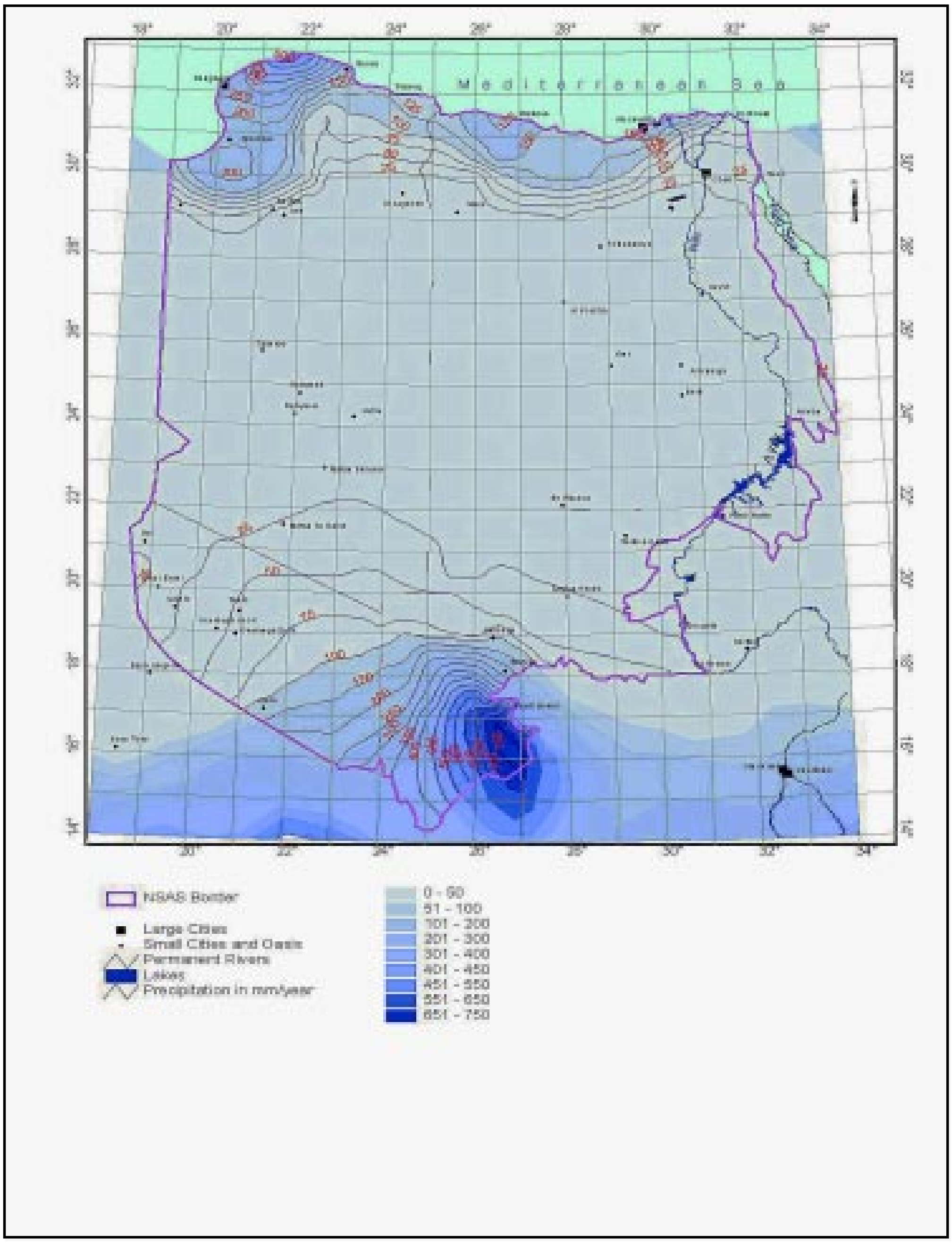

Figure 3.25: Rainfall distribution on the fringes of the Nubian Sandstone Aquifer System

Source: ArcAtlas, ESRI

The climate in the area is characterised by:

- Low and irregular rainfall;
- High daily and seasonal temperature variations;
- Low relative humidity and high evaporation intensities;
- Strong, dry winds; and
- Intensive solar radiation.

The major issues regarding water resources management in the area are the mining of fossil groundwater and the potential pollution of groundwater.

Vulnerability Indicator: Water Availability
The Nubian Sandstone Aquifer System is a non-renewable water resource, and hence the population it sustains is vulnerable to future water availability risks. Although current water use from the aquifer (about 1.7 km^3/year) is still within permissible regional limits, which could sustain the existing population for many years to come, the decline in groundwater levels has already reached 30 metres at some locations in the aquifer. This indicates that vulnerability to water availability risks is already occurring at a local level – and may become more widespread if the effects are propagated on a regional scale.

Socio-Economy
The total population in the area encompassing the Nubian Sandstone Aquifer System is estimated at 762,000, including 284,960 in Sudan (37%), 219,090 in Libya (29%), 184,770 in Egypt (24%), and 73,180 in Chad (10%). The NSAS area in Libya is generally a desert area, where communities are only resident in the oases.

The socio-economic situation of the area is characterised by:

- Low income levels;
- Relatively large household sizes;
- Relatively high mortality rates in some areas;
- Existence of different ethnic groups;
- High rates of unemployment; and
- High rates of illiteracy.

Economic activities are primarily focused on agriculture, animal husbandry and mining.

Management
Each of the four countries within the area of the NSAS has its own national development plan for groundwater utilisation. The transboundary and non-renewable nature of the resource, however, underpins the urgent need for regional cooperation in order to develop and implement a shared vision for the sustainable long-term management of the aquifer system as a whole.

Within this context, the four countries have established the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer. The Centre for Environment and Development of the Arab Region and Europe (CEDARE) was tasked in 2001 to formulate a regional programme to develop a strategy for the utilisation of the NSAS (CEDARE, 2001). Within this programme, data and information available on the aquifer system in the four countries were collated and harmonised in order to develop a comprehensive regional information system. Regional GIS maps were produced and a mathematical groundwater model constructed to predict the aquifer's response to various water development scenarios. The model, which tests the regional behaviour of the aquifer and the influence of water development scenarios in existing and future well fields, is an important tool for predicting and reducing future vulnerability to water availability. Capacity building of national institutions also formed an integral part of the programme.

3.4.3 Overview of the Nile River Basin and Nubian Sandstone Aquifer System

A brief summary of the main aspects of water resource vulnerability in the Nile River Basin and the Nubian Sandstone Aquifer System is presented in Table 3.11 below. The table is designed for illustrative rather than comparative purposes, as one of the water sources is a river basin and the other purely a groundwater basin.

Table 3.11: Water resource vulnerability in the Nile River Basin and Nubian Aquifer System

Cluster	Vulnerability Indicator*	Nile River Basin	Nubian Aquifer System
Physiography	Aridity	~40% of the area	~95%
	Water availability	Vulnerable	Stressed
	Storage and supply infrastructure	Well developed in downstream course	Poor
Socio- Economy	Population density	55 persons/km^2 downstream increase; variable	0.35 persons/km^2 variable
	Access to safe water	70%	75%
	Water use	Agriculture ~80%	Agriculture ~90%
	Poverty	High	High
	Conflicts	Moderate	Moderate
Management	Sector reform	In progress	In progress
	Implementation and adaptive capacity	Reasonable	Moderate
	Data availability, gaps and quality	Moderate	Moderate to bad

4

Synthesis

The two basic functions performed by the environment are the "source" or production function, which supports the livelihoods of millions of people who depend on environmental resources, and the "sink" or pollution absorption and cleansing function, which is essential for human health and wellbeing. Not only are these two functions closely connected in a cycle of production and renewal, but they are also being increasingly impaired and degraded by a complex combination of social, economic and climatic factors, which in many cases threaten their very existence (UNEP, 2003).

The impacts of global environmental change have been most severe in the least developed countries, and particularly affect the poor – those sectors of society that are least able to buffer their livelihoods and development against these impacts. The vulnerabilities resulting from environmental change must therefore be key targets in any practical poverty reduction programme.

4.1 Key Issues

The similarities and differences in the vulnerability of water resources to environmental change between the four regions of Africa, and between the river basins in each, were derived from the assessments presented in the previous chapter. In this chapter, key issues are formulated on the basis of these similarities and differences, and grouped in the following three clusters: physiography (4.1.1), socio-economy (4.1.2), and management (4.1.3). Regional examples illustrating the key issues are presented in the boxes.

4.1.1 Physiography

Climate Change and Variability
Africa is extremely vulnerable to climate change and variability. Rainfall variability has led to widespread incidences of drought and flooding. Global change scenarios predict an increasing frequency of drought and flooding, thus increasing the vulnerability of Africa's water resources.

Southern Africa: This region is already among the most drought-prone in the world. Indications are that climate change will result in increased rainfall variability and more frequent droughts and floods, posing serious challenges to water and food security throughout the region. Overall, climate change will result in reduced runoff and groundwater recharge in large parts of the region.

Western Africa: While drought has been a common feature of the Sahelian zone since the 1970s, floods also periodically affect the coastal belt. Reduced rainfall and increasing evaporation are predicted across most of the region, and countries in the coastal zone are expected to experience more intense rainfall and increased runoff. A decrease of 20% in rainfall has already resulted in a drop of over 40% in river flows.

Ecosystems
Ecosystems provide a wide range of natural resources (including fisheries and forestry) that support local communities. Both climate variability and water availability and quality impact upon the productivity of these ecosystems. Droughts, overgrazing and poor agricultural practices, deforestation and reclamation of wetlands for agriculture are all combining to accelerate the rate of desertification in Africa.

Eastern Africa: The Lake Victoria Basin contains some of the region's most productive wetland systems, which are vital to local and regional socio-economic development and biodiversity. Recent modifications in land use, overexploitation of the resource base (water), pollution and demographic changes all threaten degradation of the ecosystem's integrity.

Water Availability, Distribution and Pollution
Water resources in Africa are limited, unevenly distributed and often over-exploited. Pollution of water resources is also a growing concern.

Southern Africa: This region is characterised by uneven distribution and availability of water resources. A large part is arid or semi-arid. Water availability in the Orange River Basin is already at a critical stage. Pollution of water resources caused by gold mining in South Africa and by changes in land use such as deforestation is a growing concern. Deterioration of water quality by municipal and industrial effluent loading, which is further aggravated by increasing population pressures, may exacerbate the outbreak of water-related diseases such as malaria and cholera.

Eastern Africa: Eastern Africa receives most of its rain from the monsoon system. The climate is equatorial, with great (inter-annual) variation and unpredictability in the amounts and distribution of rains. The groundwater potential in the region is extremely variable – spatially and temporally, and in quality and quantity. Lake Victoria is becoming increasingly polluted as a result of sedimentation and discharge of municipal, industrial and agricultural effluent. Further deterioration of the water quality is expected with an increasing population.

Western Africa: Water resources here are characterised by extreme variability over both space and time. Some of the countries are well endowed with water resources, while others face serious freshwater shortages. There is a serious concern about the quality of water. Even when perennial surface water is available, its consumption in an untreated state presents a serious risk for human health because it is frequently contaminated by pathogens. The Senegal River Basin is particularly vulnerable to pollution in areas where layers of quarternary sediments are thin and intensive agriculture and flooding take place. Pollution through oil spillages remains a potential threat to Nigeria's water resources in the Delta.

Northern Africa: A large portion of the region depends on groundwater as its main source of fresh water. The aquifers are mostly non-renewable (fossil), whereas the main source of surface water is the River Nile. Shallow aquifers are already over-tapped in many instances. Groundwater resources in coastal regions suffer from salinity problems due to seawater or saline water intrusion. Surface water pollution (Nile River and tributaries) also results from a lack of proper waste(water) disposal and treatment, and originates from municipal waste, industrial effluent and agricultural drainage.

4.1.2 Socio-Economy

Population Growth and Urbanisation
Increasing freshwater demands are resulting from high population growth rates of up to 3%, and threatening decreasing per capita availability. High urban population growth rates of up to 6% and uncontrolled urbanisation are exerting pressure on the physical, human and financial resources required to provide safe drinking water and sanitation.

HIV/AIDS and Water-Related Diseases
HIV/AIDS is multiplying and accelerating the problems faced by the African continent, including poverty, illiteracy, erosion of social values and family life. It has crippled education and health services, destroyed households and affected business productivity. The health of the majority of the population is still affected by waterborne and water-related diseases, such as malaria, guinea-worm, cholera, typhoid, bilharzia, etc.

Southern Africa: This region suffers the world's highest prevalence of HIV/AIDS, together with one of its most widespread incidences of malaria. These diseases are further eroding the human resource base, and limiting the development, security and economic growth of the entire region. The impact of HIV/AIDS on water demand, water supply, and water and sanitation service provision needs to be analysed in greater detail and integrated into water and sanitation policy frameworks.

Access to Water and Sanitation
The relatively poor water and sanitation coverage and service delivery are mainly a result of Africa's low economic development status. The socio-economic consequence is that a large part of the population is very vulnerable to waterborne diseases. Access to water and sanitation varies from region to region and from country to country.

Water Use
Agriculture is the predominant economic activity in most African countries. Water for agricultural use will continue to command the highest demand.

Economy
Africa has the poorest economies in the world and its highest poverty levels.

Southern Africa: In one of the poorest and most underdeveloped regions in the world, resources are often not available for the construction of proper water supplies and the implementation of effective management initiatives. High population growth rates and urbanisation are placing further constraints on financial resources.

Water-Related Conflicts
In several African countries, the scarcity of water supplies has effectively limited further development due to high population growth rates accompanied by increasing water demands. Ideally, each country's water resources management strategy needs to be aligned with that of its neighbours if peace and prosperity are to be maintained and water-related conflicts are to be avoided (Ashton, 2002).

Eastern Africa: Current economic and environmental trends reveal increasing competition over access to and use of freshwater resources, at the same time that population growth, industrialisation and potential climate change are adding stress to these resources. In the Rufiji River Basin, for example, competition for land and water is growing between poor pastoralists and farmers, while competition for water is also high between irrigators and hydropower stakeholders.

Northern Africa: Water problems in the upstream part of the Nile River Basin are more related to drainage, flood protection, occasional droughts and drinking water infrastructure, while those downstream are more related to water scarcity. Once these problems are clearly identified and understood, there could be great potential for cooperation rather than conflicts, e.g. with upstream countries using surface waterways for power generation, which could then be used for groundwater development in remote areas for drinking water purposes and supplemental irrigation during drought periods.

4.1.3 Management

Institutional and Legislative Frameworks
There is generally a shortage of know-how and institutional 'strength', which has limited the success of water resource management initiatives to date.

Data Availability, Access, Sharing and Standardisation
Data availability is mostly according to administrative boundaries and not according to hydrologic (river/lake/groundwater basin) boundaries. The number of monitoring stations in Africa is limited and there is an information bias towards water quantity against quality, and a bias towards surface water against groundwater. Access to databases is often restricted and transboundary information-sharing is limited. The harmonisation of databases is required as well as uniform procedures and data-collection methods.

Southern Africa: In comparison to other countries in the region, South Africa has a wealth of information available on surface water and groundwater resources.

Eastern Africa: Collaboration is needed to put databases to use for international projects. Data quality has been hampered by inconsistencies and by the length of available records, resulting from breakages of instrumentation or conflicts in some countries.

Western Africa: Since 1974 the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) has: (a) collected and managed data on climate, hydrology, soils and socio-economic issues; (b) disseminated climatic information to member states and other target groups; (c) established an early warning system based on weather data, agro-ecosystem models, and geographical information systems; and (d) carried out research and training through its AGRHYMET Regional Centre.

Northern Africa: There is a clear need for a Nile water database for harmonising data collection and information management.

Monitoring
The extent to which data on water resources is available also depends on the extent to which data-gathering programmes have been implemented. Long-term data gathering is required to enable proper analysis of the impact of environmental change on water resources.

Knowledge Gaps
Areas that have been identified that contain significant knowledge gaps include climate change and variability, water pollution, groundwater recharge and environmental flow.

Climate change and variability studies: Advanced studies are required on climate change and its impact on water resources, and there is a need to incorporate the results of such studies in (regional) water resource assessments.

Eastern Africa: The region has experienced at least one major drought per decade over the past 30 years. There were serious droughts in 1973/74, 1984/85, 1987, 1992-94 and 1999/2000. There is also some evidence of increasing climatic instability in the region, and increasing frequency and intensity of droughts.

Western Africa: The decrease of rainfall in the Sahel is closely linked to a decrease in the number of rainfall events. The main challenge for researchers, therefore, is to determine the causes of the decrease in rainfall events and to indicate how climate variability can be taken into account to improve water resource management strategies.

Water pollution: There is a bias towards information on water quantity rather than water quality. Issues of (ground)water quality and pollution have not yet been adequately addressed.

Eastern Africa: The causes of pollution in Lake Victoria Basin have not been adequately established and quantified.

Western Africa: Groundwater quality has not been adequately addressed.

Groundwater recharge: There is very little accurate data available on groundwater recharge – despite this being a critical parameter for determining water availability and scarcity.

Southern Africa: Despite the great number of recharge studies undertaken in the region, more work is needed before reliable maps can be produced depicting spatial and temporal variability in recharge at local and regional scales.

Environmental flow: Knowledge on environmental flow requirements remains very limited across the continent.

4.1.4 Water Scarcity

Water stress is expected to have increased in most African countries by the year 2025.

Southern Africa: When water availability is combined with the relatively high demands and withdrawals for agricultural use, the Orange River Basin is among the most severely water scarce regions in Africa. Two Southern African countries that are expected to experience increased water scarcity by 2025 are South Africa and Malawi, whereas Lesotho, Tanzania and Zimbabwe will become water stressed.

Eastern Africa: Countries expected to experience severe water scarcity by 2025 are Ethiopia, Kenya and Somalia. Increased water stress, caused by prolonged periods of low rainfall and/or increased water demand, will also affect countries that depend upon hydroelectric power, such as Kenya and Uganda.

Western Africa: Six Western African countries are expected to experience water scarcity by 2025, namely Benin, Burkina Faso, Ghana, Mauritania, Niger and Nigeria. Most other countries in the region are already constrained by inadequate water supplies. The Niger River Basin is considered to be one of those most affected by freshwater shortages in the region.

Northern Africa: It is expected that water scarcity will have increased dramatically across the region by 2025, particularly for the northernmost countries.

4.2 Adaptation and Mitigation Options

4.2.1 Institutional and Legislative Frameworks

Water Sector Reforms

Southern Africa: There has been significant progress in water sector reforms in Southern African countries since the early 1990s, with an increasingly integrated approach to water resources management. Integrated Water Resources Management (IWRM) approaches that recognise the connection between water, land, human development and the natural environment are being adopted.

Eastern Africa: Multi-sectoral frameworks are being developed to enhance the potential for adaptation to environmental change and these should strengthen wetland and lake management, including the conservation of critical national and transboundary habitats.

Western Africa: The institutional framework and water-related legislation and guidelines are relatively well-developed in the Senegal River Basin. Although not as well established, in the Niger River Basin, progress is being made by the Niger River Basin Authority (NBA) to promote appropriate water-related legislation and to establish new institutions.

Northern Africa: The riparian countries of the Nile River Basin are being encouraged to develop and integrate national water master plans into a Nile Basin Action Plan designed for the sustainable integrated management of the Nile Basin's water resources.

Managing (Shared) Waters and Ecosystems

Southern Africa: In recognition of the importance of a coordinated approach to the utilisation and preservation of shared water resources, the SADC states signed the Protocol on Shared Watercourse Systems in 1995. This protocol has formed the basis for the establishment of River Basin Commissions.

Eastern Africa: Issues related to the management of international waters are being addressed at various forums and regional bodies, such as TECCONILE. Ratification advancements of the East African Community Treaty widen the scope for such regional institutions to manage shared ecosystems.

Western Africa: River basin organisations have been established for the Niger, Senegal and Gambia Rivers and for Lake Chad. In the case of the Volta River, an informal arrangement for consultation has been made between Ghana and Burkina Faso.

Northern Africa: The Nile riparian countries established a forum to facilitate a process of legal and institutional dialogue in 1997. In early 2000, a panel of experts produced the draft text of a Cooperative Framework document. The Council of Ministers agreed in August 2000 to extend the process to further dialogue on outstanding issues. Improved cooperation between stakeholders is clearly needed to ensure coordination and to develop a common strategy for water management among ministries and governmental institutions.

Communities' Response to Water Stress

All Regions: Further efforts are required to promote the adoption of technologies and management approaches that increase the efficiency of water use, allocation and distribution (e.g. water conservation techniques and the reuse of wastewater), as well as the implementation of environmental protection measures (e.g. planting trees and establishing nurseries).

4.2.2 Capacity Building

Capacity for Resource Management

All Regions: With limited water management capacities across the continent, capacity enhancement programmes must urgently be implemented at various academic and institutional levels to facilitate appropriate IWRM.

4.2.3 Data and Monitoring

All Regions: Major improvements are required in various fields, including:
Data rescue - Programmes should be initiated for the archiving, processing and analysis of historical data;
Standardised assessments - There is a clear need for a comprehensive standardised water resources and water use assessment and for the harmonisation of national databases;
Monitoring - Monitoring of water quantity and quality must be improved for reliable early warning systems and effective water management.

4.2.4 Technologies

All Regions: Various technological developments should be explored to improve the utilisation and management of freshwater resources, including:
Dam storage and increased groundwater use - to cope with increasing variability in water resources, to control river flows and mitigate the occurrence of flood and drought events.
Conjunctive water use - including rainwater harvesting.
Improvements in urban water supplies
Investments in wastewater treatment
Improvements in agricultural techniques - including cropping types, irrigation techniques and irrigation timing.
Water trade - as an element of adaptation strategies designed to combat water scarcity and food insecurity resulting from e.g. global environmental change. Trading in water can be an instrument in solving geopolitical problems and preventing potential conflicts over water. Ideally, this relatively new concept could form a basis for drafting water policy plans at local, national and regional (transboundary) levels.

5

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