“Vulnerability of Water Resources to Environmental Change in Southern Africa”

A report for the Pan African START Secretariat and UNEP

by

Hans E. Beekman, Irené Saayman and Simon Hughes

November 2003

Council for Scientific and Industrial Research
PO Box 320
Stellenbosch 7599
South Africa

CSIR
ENVIRONMENTEK
Your Technology Partner

Table of Contents

LIST OF FIGURES

LIST OF TABLES

TEXT BOXES

1 INTRODUCTION

1.1 Background

The availability and access to water strongly influences patterns of economic growth and social development (Alan, 2002). In this regard, the Southern African region 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 in the context of integrated water resource management (IWRM) with its main principles of equity (regarding access), efficiency (economic) and sustainability (environment).

The sub-Saharan region is characterised by a high economic dependence on local natural resources in the form of agriculture (frequently subsistence) and pastoralism, in which the variability of climate and the availability of water to a large extent determine production. This coupled with its relatively low development status make the economies and social character of Southern Africa particularly vulnerable to changes in the availability of water over space or 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 or the onset and duration of the rainy season (Schulze et al., 2001) or in terms of the quality of the available resource. The extent to which water resources, the environment and economies may be impacted by changes in water availability vary.

In February 2003 the UNEP Project "Vulnerability Assessment of Water Resources to Environmental Change in Africa" was launched to address the vulnerability issue in a broad sense, i.e. in terms of physiographic, socio-economic and management related changes. This report presents the Southern African contribution to this project.

The Southern Africa assessment is carried out in the context of the recent World Summit on Sustainable Development (UN, 2002) where the international community made a renewed commitment to sustainable development as outlined in the Rio Declaration (UN, 1992) and the advancement of the Millennium Development Goals (UN, 2000). These recognise that sustainable development in Africa can only be achieved by addressing peace, security and development concerns, including issues related to the environment, human rights and governance. This overlaps with efforts in formulating "a programme of action for Africa's re-development" through the NEPAD initiative (www.nepad.org).

1.2 Terms of Reference

For the Southern Africa project the following deliverable was defined:

"A Report with data and information on vulnerability of water resources in Southern Africa and policy actions derived from stakeholder consultations and assessment for the future GEO report"

Main focus of the project is to:

- Conduct a comprehensive review of existing vulnerability assessments of water resources, to synthesize results of various scientific studies, integrate data and information from multiple sources and identify indicators that would best represent the type of vulnerability studies that are to be pursued.

- Carry out Southern Africa vulnerability assessments on issues where investigations have so far been inadequate and where water resources are believed to be highly vulnerable to environmental change.

Activities should focus on river/lake basin scale with special attention on:

- Water Stress (combined effects of different stresses acting upon regional water resources);
- Water supply and allocation (water stocks and uses including optimal allocation of water resources to benefit people's livelihoods and support economic growth of the region);
- Water management policies (the physical, social, economic and legal aspects of water resources, management and development);
- Environmental change threats to water availability (including natural and socio-economic systems, changes in land-use, climate change etc);
- Link between the vulnerability of water resources to environmental change and contribution of poor water quality to human vulnerability. Identification of human impact in highly populated areas in order to minimize existing or potential vulnerable water resources (surface) contamination at the source.

1.3 Report Structure

Section 2 provides a framework for the vulnerability assessment. This framework comprises definitions of vulnerability, the motivation for a river basin perspective on vulnerability assessment, identification of parameters and vulnerability indicators and a three-tier approach to vulnerability assessment.

Section 3 presents a general vulnerability assessment of water resources to environmental change for the Southern African region as a whole and a more detailed assessment (‘rapid’ approach) of the two largest river basins: Zambezi and Orange River. The assessments concentrate on various aspects of vulnerability seen from physiographic, socio-economic and management points of view.

In *Section 4* the vulnerability assessments of the river basins are compared and key issues to be included in future analyses are discussed.

Section 5 gives an overview of references and data sources (including web-sites).

2 FRAMEWORK FOR VULNERABILITY ASSESSMENT

2.1 Definitions

The degree to which a system is susceptible to, or unable to cope with, adverse effects of environmental change, including natural and socio-economic systems, defines its **vulnerability**: With regard to climate change this vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2001). Of most concern and relevance to the discussion on the vulnerability of water resources are spatial and temporal changes in precipitation.

In many countries water demand outstrips the available freshwater resources. Countries or regions where such conditions limit development are said to experience **water stress**. Water stress may cause the deterioration of fresh water resources in terms of quantity (over-exploitation, environmental degradation, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). Withdrawals exceeding 20% of renewable water supply has been used as an indicator of water stress (IPCC, 2001). Appropriate **water resource legislation and management** is a means to address vulnerability issues.

2.2 River Basin Perspective

Increased incidence of water stress have brought about the adoption of new approaches to the management of the water resources in a holistic and integrated manner. A paradigm shift from water resource management based on administrative boundaries to hydrological boundaries followed from the Rio + 10 and Dublin conferences.

The River Basin perspective takes into account the different components of the hydrological cycle. The 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 is meant to denote desirable collective goals such as equity, voice, self-realization and a healthy environment (Turton and Henwood, 2002). In effect, the River Basin perspective seeks to maintain a balance between the competing pressures exerted by the need to maintain resource integrity in the long-term, against the compelling call for social upliftment and advancement, and the need for continuous economic growth and use of environmental resources.

The River Basin perspective represents a progression from supply orientated water resource development to water demand management (Turton and Henwood, 2002). This progression develops where water demand continues to outstrip supply even though all available water sources have been developed or are prohibitively expensive to develop, which induces competition between water use(r)s and 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).

For this project we will carry out a general assessment for the Southern Africa region as a whole and a more detailed assessment for two large river basins.

2.3 Parameters and indicators

Parameters and related indicators for assessing vulnerability of water resources to environmental change were grouped into natural, socio-economic and management clusters (see Table 1). They have been linked to sub-clusters and should be applied at various temporal and spatial scales. Please note that the table is not exhaustive but aims at providing an overview of those parameters and indicators for which data and information is relatively easily available and accessible from a Southern African perspective, i.e. according to the knowledge of the authors of this report. The reader is referred to Chapter 3 for detailed discussions on the parameters and indicators.

Table 1: Parameters and vulnerability indicators.

Cluster		Parameter *	Vulnerability Indicator*	
Physiography	Climate	• Rainfall, • Evapotranspiration	• Aridity	**Water Scarcity**
	Ecosystems	• Water dependency • Land use • Landcover		
	Hydrology	• Stream flow	• Water Availability • Storage and Supply Infrastructure	
		• Storage • Quality		
	Hydrogeology	• Yield • Recharge		
Socio- Economy	Demography	• Population Size and Distribution	• Population Density • Access to Water	
	Economy	• Water Demand • Water Supply • Value of Water	• Water Use • Poverty • Conflicts	
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 Approach to Vulnerability Assessment

The level of detail of a vulnerability assessment is determined by the study objective and resource availability (human resources, finances, data and information, etc.). We propose the following three tiered approach:

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

We estimate that it should take one month for one person to carry out a vulnerability assessment of one large river basin to the level of a rapid assessment. The subsequent intermediate assessment may take about six months, depending on the study objective, whereas the comprehensive assessment may take a year.

The following procedure is proposed for carrying out a rapid assessment:

Stage 1: Define spatial scale of assessment using biophysical and socio-economic boundaries.
Stage 2: Define temporal scale that incorporates current and potential environmental change.
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 study area.
Stage 5: Provide a summarised overview.

Data availability and knowledge gaps should be inventorised during the rapid assessment, preferably at a river basin scale.

Table 2 provides a means to evaluate data availability and knowledge gaps during the rapid assessment. Data availability can be referenced on a country (national) and regional (Southern Africa) level, and grouped according to the main vulnerability assessment clusters and sub-clusters. Having been collected nationally, country-by-country, information in Africa, however, is generally compiled and available according to administrative boundaries rather than according to hydrological boundaries. Information therefore needs to be synthesised. Geographical Information Systems (GIS) offer an opportunity to capture and assemble information at the River Basin scale. For a comprehensive vulnerability assessment the data inventory should include metadata describing its reliability and precision, as well as the temporal and spatial scale for which it is representative.

Table 2: Data availability and knowledge gaps.

	PHYSIOGRAPHY					**SOCIO-ECONOMY**			**MANAGEMENT**					
COUNTRY / REGIONAL	**Climate**	**Climate Change and Impacts**	**Ecosystems**	**Hydrology**	**Hydrogeology**	**Sociology - Health**	**Hydro-politics**	**Economy**	**Legislation, regulations and guidelines**	**Water Sector Reform – IWRM**	**Water Master Plan**	**Data-bases and Maps**	**Digital Coverage**
A	🟨	🟨	⬜ 🟨	⬜ 🟨	⬜ 🟨	🟨	🟨	🟨	⬜ 🟨	🟨	⬜	🟨	🟨
B			⬜	⬜	⬜				⬜		⬜		

🟨 Africa / Southern Africa
⬜ Country-specific

3 VULNERABILITY ASSESSMENT OF SOUTHERN AFRICA

3.1 Southern Africa

The four largest Southern African (internationally shared) river basins, south of the Democratic Republic of Congo, are (from largest to small) the Zambezi River Basin, the Orange River Basin, the Okavango River Basin and the Limpopo River Basin. The distribution of these river basins over the sub-continent is shown in Figure 1.

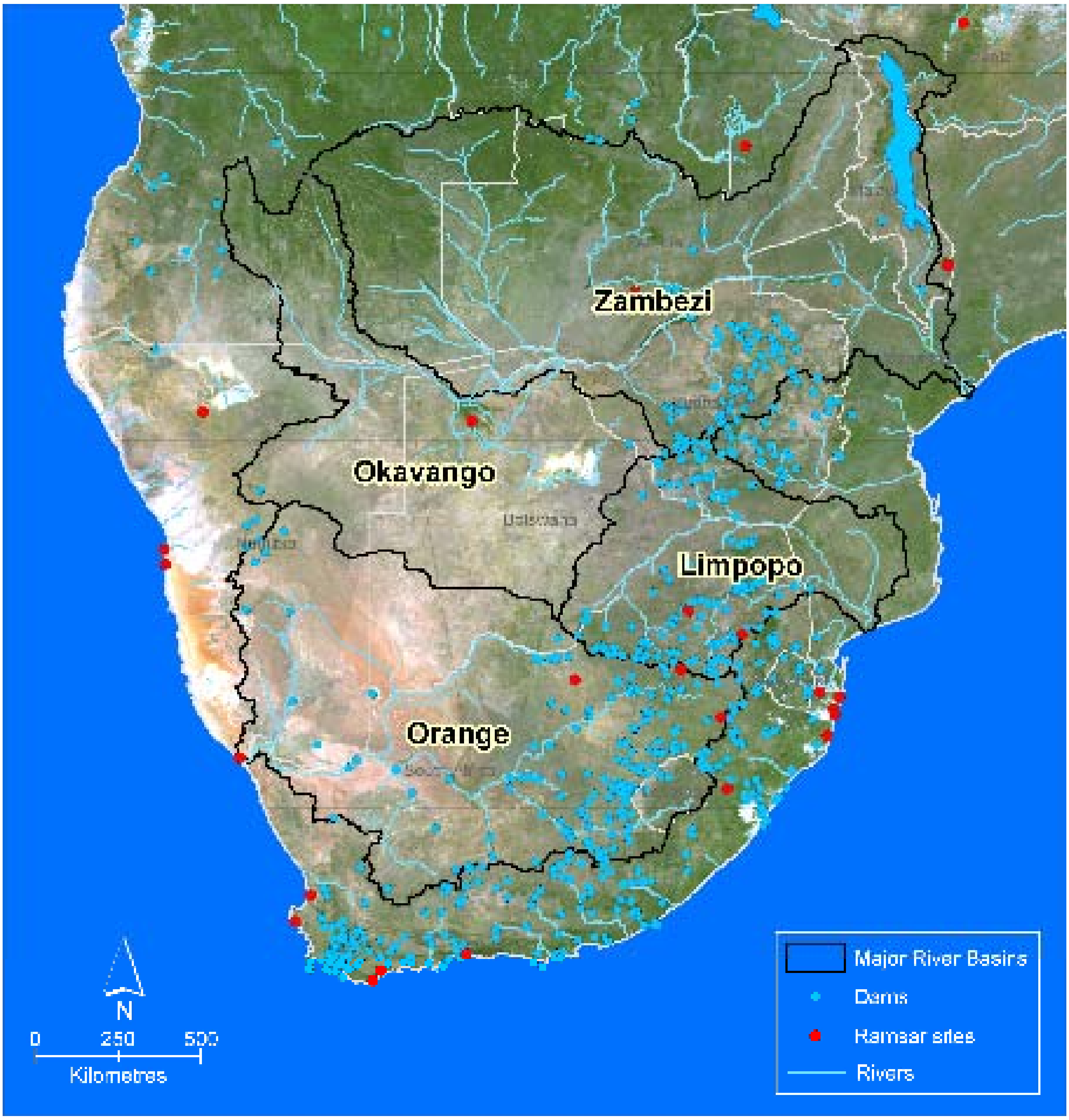


Figure 1: Major River Basins of Southern Africa.

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

3.1.1 Physiography

Climate

Rainfall patterns of Southern Africa are largely governed by the position of three systems; the Intertropical Convergence Zone near the equator, high-pressure cells south of the 20° parallel, and cold fronts at the southern tip of the continent. Broadly speaking, annual rainfall is highest near the equator and along the east coast, and decreases southwards and westwards. It ranges from 100 mm in the western parts to 1500 mm in the eastern parts. Potential evapotranspiration exceeds average annual rainfall in most of the region. An average of 65% of all rainfall evaporates soon after it has fallen (Pallett, 1997). Evaporation is much lower in relatively cooler and more humid areas, but can get as high as 83% in Namibia.

Ecosystems

Natural beauty and biological diversity (birds and wildlife) are one of the key attractions for tourists. The region has relatively large areas where the natural systems are protected and largely un-impacted by human interventions. Recent developments have seen the joining of protected areas across national borders through the establishment of trans-frontier parks. Furthermore, there are 25 wetlands of high ecological importance in the region protected under the Ramsar Convention of 1971 (Figure 1).

The region's landcover largely mirrors its 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 2). This to some extent is a reflection of the relatively advanced level of commercial agriculture that exists in these countries.

Hydrology and Hydrogeology

Renewable freshwater of Southern Africa is estimated at 650 billion cubic meters, distributed over rivers, lakes and groundwater (Chenje and Johnson, 1996). The distribution, occurrence and availability of water resources are uneven in the region. In some parts of the region surface runoff is available in sufficient quantities throughout the year. In other parts surface runoff only occurs with extreme episodic rainfall events. Under such conditions people rely largely on dams and groundwater resources. The renewable portion of groundwater resources is determined by groundwater recharge. Average annual recharge figures for the region typically range from 1 to 15% of average annual rainfall (Gieske, 1992; Bredenkamp et al., 1995; Beekman et al., 1996; Xu and Beekman, 2003).

Southern Africa has 16 major river basins, of which the four largest are the Zambezi River, the Orange River, the Okavango River and the Limpopo River Basins (Figure 1). The Zambezi and Limpopo rivers flow into the Indian Ocean, while the Orange River flows into the Atlantic Ocean. The Okavango River Basin is internally draining and terminates inland in the Okavango Delta.

Groundwater is extensively used throughout Southern Africa (Savenije and van der Zaag, 1998). This is particularly the case in rural areas where groundwater is the main contributor for domestic supply and agricultural needs. Figure 3 illustrates the distribution of groundwater occurrences according to the following main hydrolithological domains: volcanic rocks (e.g. basalt); Precambrian basement rocks (crystalline basement); consolidated (e.g. sandstone and dolomite) and unconsolidated (e.g. sands) sediments. Southern African aquifers mainly occur in crystalline basement and sedimentary basins. Although the hydrolithological domains do not follow the river basin boundaries, the aquifers generally do fall within the boundaries.

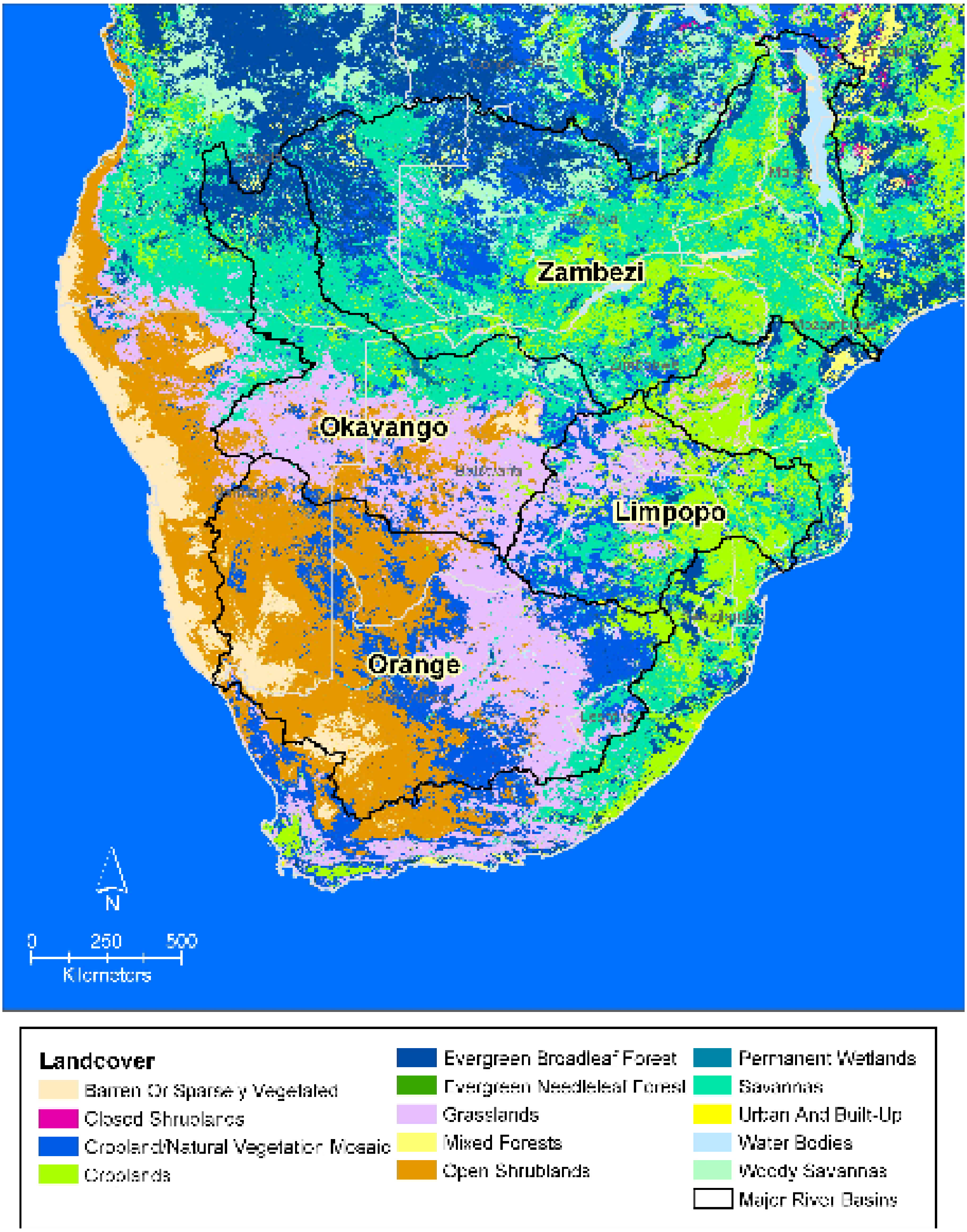


Figure 2: Landcover Southern Africa (IGBP Legend).

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

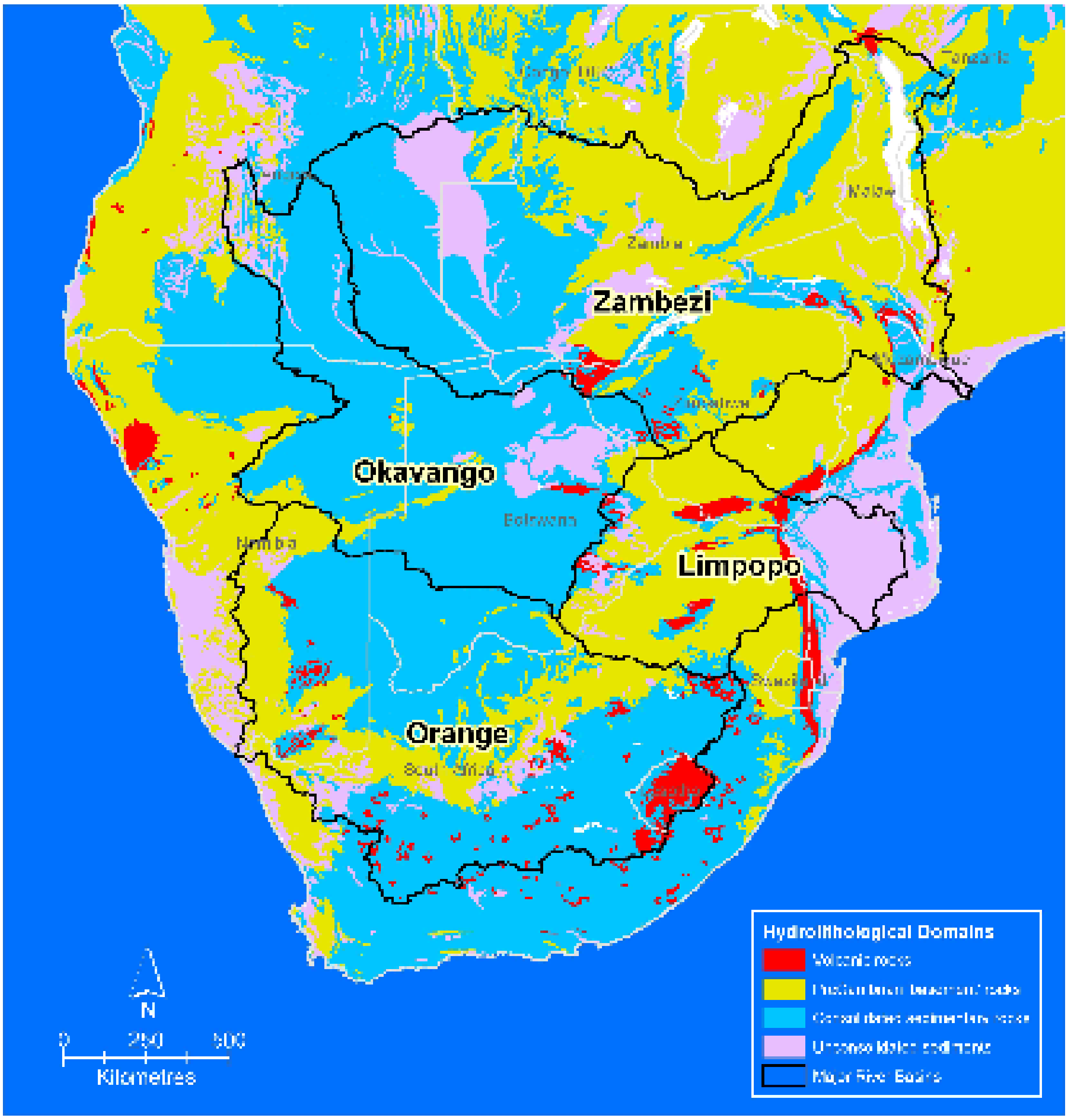


Figure 3: Hydrolithological Domains of Southern Africa.

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

On top of crystalline basement a weathering zone may develop which is usually 10 to 15 meters thick (UN, 1988). Groundwater yields from boreholes in these zones depend on the degree of weathering and fracturation of the rock. Borehole yields of 5 m^3/hr for granites and granitogneiss and 1 m^3/hr for micaschists and metamorphic schists are considered as 'good' (UN, 1988). Groundwater from these rocks is mostly used for domestic water supply.

Vulnerability Indicators

Aridity

Figure 4 shows the aridity in the region as a function of rainfall and evapotranspiration and is indexed as: Annual Precipitation / Annual Potential Evapotranspiration. The lower the

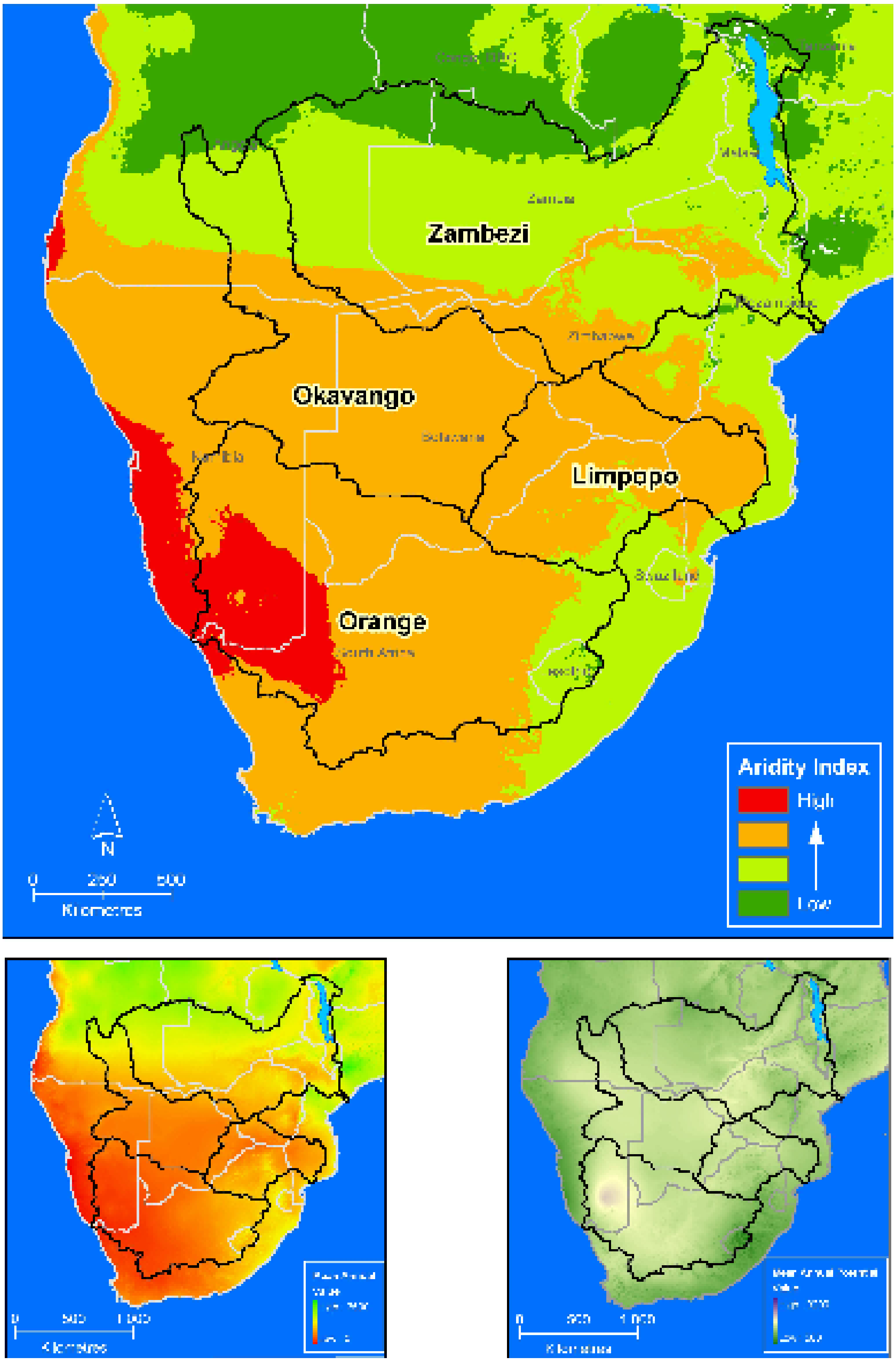


Figure 4: Aridity in Southern Africa.

Source
UNEP Spatial Characterisation Tool, 1997. Texas A&M University, USA.
http://www.grida.no/cgiar/awpack/spatial.htm

index, the higher the aridity and vulnerability of water resources to environmental change. Highest aridity occurs in western-Southern Africa and decreases to the north and east.

Water availability
The availability of water relates to both quantity and quality aspects. It comprises both surface water and groundwater. Availability of water is determined by parameters such as rainfall and evapotranspiration, land cover, recharge, etc. Figure 5 shows water availability per capita per year for selected countries. Projected figures for 2025 (UN FAO, 1995; Vital Climate graphics Africa – UNEP) suggest that water availability per person will decrease. This is largely due to increasing water demand and a reduction in resource accessibility as a result of factors such as increasing urban population, environmental change (incl. climatic change), pollution, etc. Particularly for Malawi and South Africa the projection looks bleak.

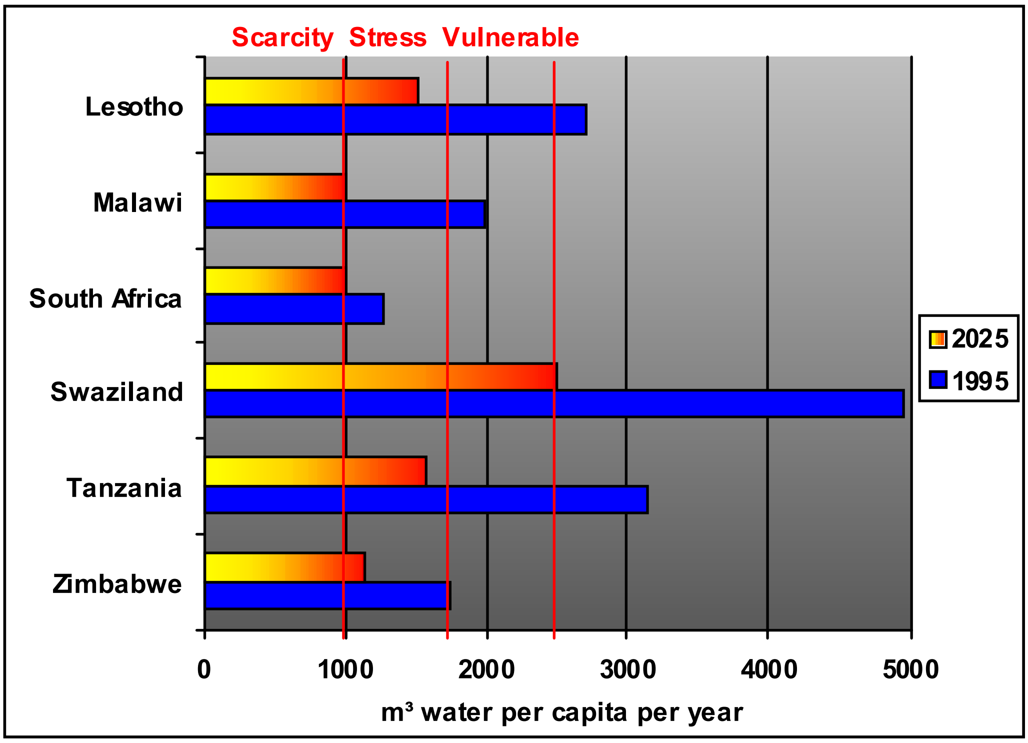


Figure 5: Water availability in selected countries (after Hirji et al., 2002).

Source
UN FAO 1995; Hirji et al., 2002; Vital Climate Graphics Africa;
UNEP Grid Arendal, 2003 www.grida.no/

3.1.2 Socio-Economy

Demography
The population of Southern Africa (excluding The Democratic Republic of Congo) was estimated to number around 150 million people in 2000 (Ashton and Ramasar, 2002). Table 3 gives a breakdown of population of each country. Population growth rates are high:1.5 – 3%, but will likely be curtailed by the spread and impact of HIV/AIDS. Note in the table the decline in life expectancy for all counties of the region between 1995 and 1999/2000. Some projections (UN World Population Prospect), however, foresee that SADC's population will grow by about 50% by 2020 and 100% by 2050.

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. Some of the main population centres can be seen in Figure 6 (from 1988 population data).

Table 3: Population size and per capita GDP (Ashton and Ramasar, 2002).

SADC country	Population in 2000 (millions)	Country population in 2025 (millions)	Per capita GDP in 1999 (US$/p/year)	HIV/AIDS incidence (%)	1995		1999-2000*	
					Life expectancy (yrs)	HDI ranking	Life expectancy (yrs)	HDI ranking
Angola	12.903	21.961	336	**2.8	50	157	47	160
Botswana	1.639	1.981	2 904	35.8	60	71	39	122
Lesotho	2.156	3.246	502	23.6	58	137	46	142
Malawi	10.778	16.068	132	16.0	46	157	39	159
Mozambique	19.980	28.776	92	13.2	52	166	43	169
Namibia	1.739	2.567	1 969	20.0	56	116	50	115
South Africa	43.265	49.010	3 281	22.6	60	100	48	101
Swaziland	0.928	1.257	1 255	25.3	58	110	46	114
Tanzania	33.744	63.636	124	8.1	50	149	45	156
Zambia	9.191	14.895	431	20.0	49	136	39	151
Zimbabwe	13.109	13.988	579	25.1	50	124	40	151

*Latest data available was for different years, either 1999 or 2000.
**Unreliable data due to civil war in these countries.

Source
World Bank (1998), CIA (2000); SADC (2000); UNAIDS (2000); Whiteside and Sunter (2000).

Large disparities exist between the levels of development in the countries of Southern Africa. One way of comparing development is through the Human Development Index (HDI) (shown in Table 3). The HDI is a composite of three basic components of human development: longevity, education and living standards. Five out of the 11 Southern African states fall in the lowest–ranking countries regarding the Human Development Index. A comparison with the rest of the world shows that sub-Saharan Africa is the most under-developed region in the world. This is illustrated by the fact that the region has the highest proportion of people relying on less than one dollar a day (Christian Aid, 2002).

In order to advance human development, governments have adopted a number of targets, known as the Millennium Development Goals MDG (UN, 2000; UN-WWDR, 2003). Among these is Goal 7, which requires that governments adopt sustainable resource management policies and reduce the number of people that do not have access to safe water and sanitation by half by 2015.

Economy

The economy of Southern Africa is largely based on natural resources, with mining and agriculture contributing most to economic output. Mineral wealth, however, is not evenly distributed throughout the region, with development concentrated in Angola (Oil), Botswana (Diamonds), Namibia (Diamonds) and South Africa (Gold, Diamonds, Platinum, Coal). Agriculture contributes 9% to the GDP output of the region (1996 data), but provide employment for 60% of the regions total active labour force (source: FAO statistics-www.fao.org).

In 2000 the Gross Domestic Product (GDP) of Southern Africa was US$162.3 billion, of which $125.8 billion (78%) was produced in South Africa (UNEC, 2002). The average sub-Saharan annual per capita income is $490, while in Botswana it is $2 904, Namibia $1 963 South Africa $3 281 and Swaziland $1 255 (Ashton and Ramasar, 2002).

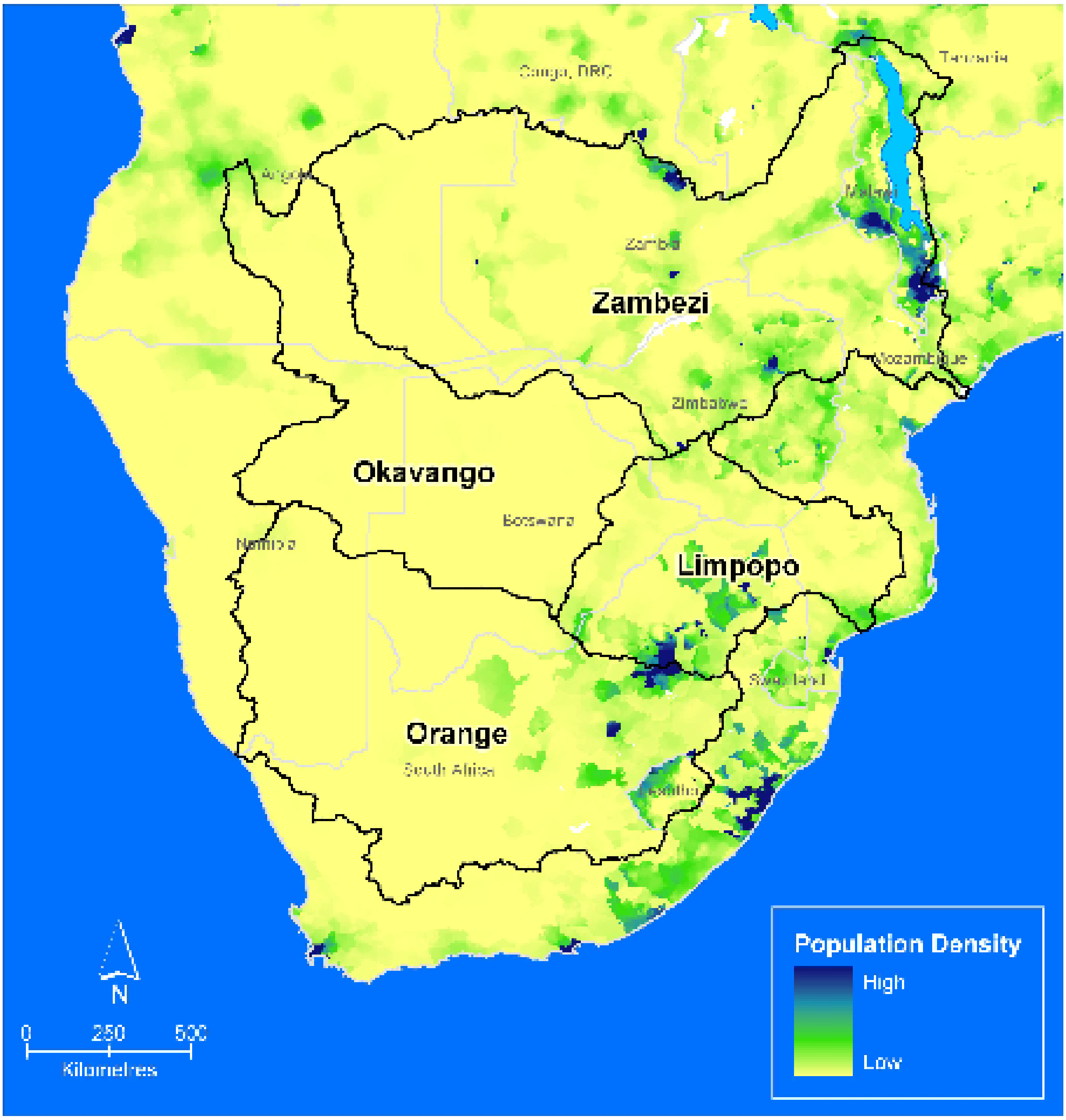


Figure 6: Population density in Southern Africa.

Source
UNEP Spatial Characterisation Tool, 1997; Deichmann, 1994.

The impact of social instability and war has constrained growth and development throughout the region. Its low development status has resulted in considerable involvement of the international community through aid and donor agencies. Large foreign dept remains a problem in the region, with Angola, Malawi, Mozambique and Zambia classed among the most indebted countries in the world (Jubilee, 2000).

The UN Economic Commission for Africa estimates that in order for countries in Southern Africa to meet the MDGs by 2015 a minimum sustained growth rate of 6.2% a year is required. In recent years only Mozambique has grown more than 6%. During the 1990s, the average growth rate in Zambia has been 1.6% and in conflict and war-ridden Angola 0.5%.

The Zimbabwean economy is the fastest contracting in the world today, with GDP shrinking by 17% in 2002 (Christian Aid, 2002).

Economic factors that contribute to the poor performance of Africa and which render most of the population vulnerable have been summarized as follows (HSRC, 2002):

- low levels of private investment due to macroeconomic instability, inadequate legal systems and conflict;
- high tax and import duty rates which discourage foreign investment;
- bad governance and corruption;
- high levels of debt and dependence on foreign assistance;
- low rates of return on capital and labour;
- low overall productivity rates;
- over-valued exchange rates;
- poor infrastructure; and
- insufficient competition and monopolistic structures.

Impact of HIV/AIDS

HIV/AIDS remains a major concern for Africa. Apart from its direct effects on the health of individuals, it also exerts indirect influences on every sector of society. HIV/AIDS further poses a threat to development, security and economic growth. Among the consequences of the HIV/AIDS epidemic is an erosion of human capacity within organisations and in countries. The loss of capacity reduces economic growth. Southern Africa is the region with the highest incidence of HIV/AIDS in the world. Of the countries of Southern Africa, Botswana (35.8%), Swaziland (25.3%), Lesotho (23.6%) and South Africa (22.6%) have the highest incidence of HIV/AIDS (Ashton and Ramasar, 2002).

Several aggregate models project significant reductions in economic growth rates for African economies. These modelling exercises typically follow a pattern of reporting “with” and “without AIDS” scenarios. An example is the widely cited ING Barings model produced for the July 2000 HIV/AIDS conference in Durban, which showed that long-term economic growth in South Africa would decline 0.4 percent per year due to HIV/AIDS (Brookings Institution, 2001). Recent research, however, suggests that these studies may be too optimistic. What they fail to consider is that by undermining human capacity, HIV/AIDS reduces productivity, disrupts organizations, and unravels institutions (Brookings Institution, 2001).

Vulnerability Indicators

Water Demand and Water Use

Based on an evaluation of water availability in Southern Africa, Arntzen (2001) demonstrated that increased water demand is driven by:

- High population growth (2 – 3.5% per annum)
- The urbanization of populations
- Improved welfare and living conditions and
- Industrial and agricultural development.

Increasing water demand and water use obviously results in less water available per person.

Conflicts (from Ashton, 2002)

Some 85% of Africa's water resources are comprised of large river basins that are shared between several countries. High rates of population growth accompanied by continued increases in the demand for water have resulted in several countries passing the point where the scarcity of water supplies effectively limits further development. 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. Normally, water allocation and distribution priorities within a country are aligned with national development objectives. While this may achieve national "water security" objectives, greater emphasis needs to be placed on regional efforts to ensure that the available water resources are used to derive sustainable long-term benefits for the peoples of Africa as a whole. Ideally, each country's water-resource management strategy needs to be aligned with that of its neighbours if peace and prosperity are to be maintained and conflict is to be avoided in the region. Figure 7 shows hot-spots of actual or potential water-related conflicts in Southern Africa. Largest conflicts are expected in connection with the Lesotho Highlands Water Project, the Limpopo River and the Eastern Caprivi region.

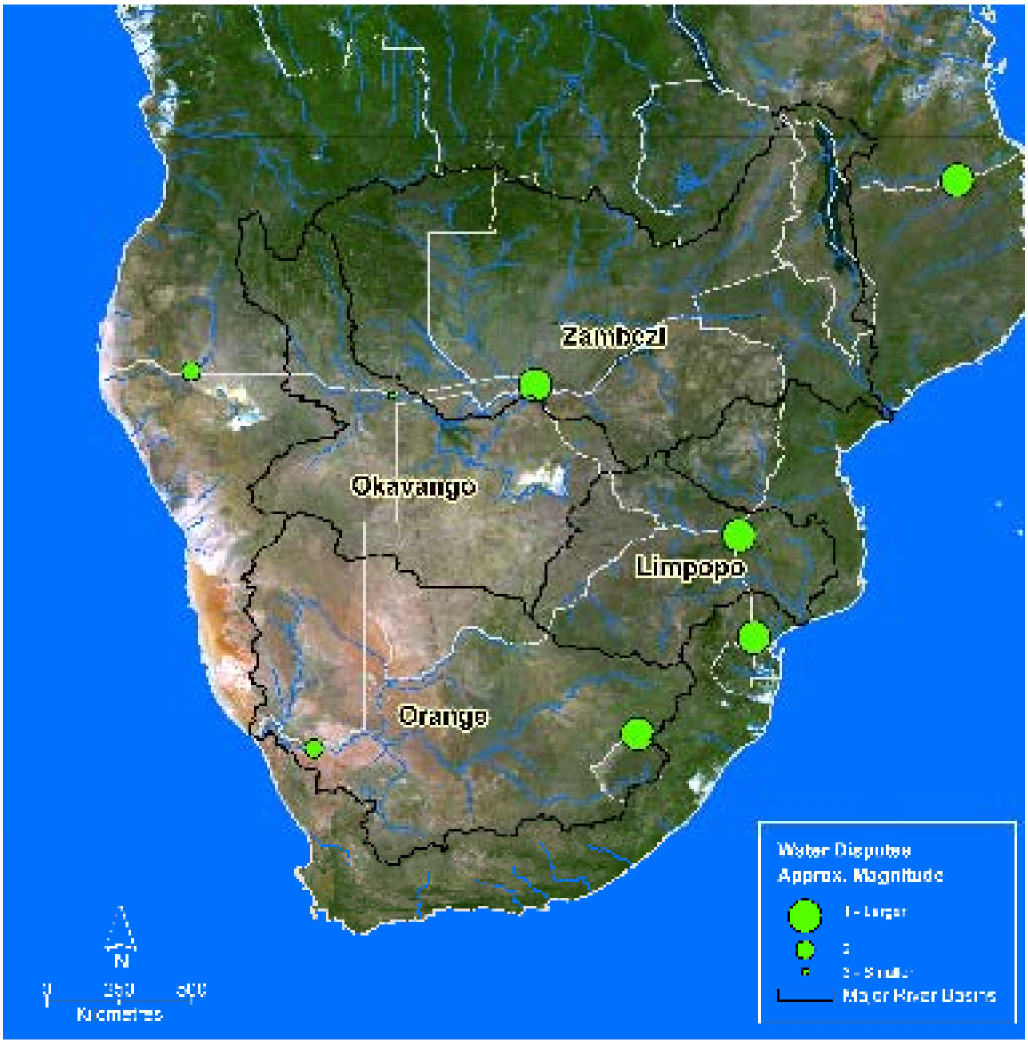


Figure 7: Potential Water Related Disputes in Southern Africa.

Source
Adapted from Ashton, 2002.

3.1.3 Management

Legislation and Institutional Framework

There has been significant progress in water sector reforms in Southern African countries since the late nineties with an increasingly holistic approach to water resource management (both surface water, groundwater, socio-economic and other issues being dealt with in an integrated manner). The water sector reforms which include the set up of new institutions with new functions and responsibilities and legislation and guidelines for water resource management and development, takes place at a different pace and at different scales. South Africa and Zimbabwe promulgated their new Water Acts in 1998 whereas other countries such as Namibia and Zambia are in the process of revisiting their old Acts.

SADC Shared Watercourse Systems Protocol (http://www.thewaterpage.com/sadcWSCU.htm)

Water in the region is a scarce resource 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 which is a legally binding document, is to ensure equitable sharing of water and also to ensure efficient conservation of the scarce resource. The protocol describes the establishment, objectives and functions and a financial and regulatory framework of River Basin Management Institutions.

As of 5 July 2001, the SADC countries that have ratified the original Protocol on Shared Water Course Systems are Botswana, Lesotho, Malawi, Mauritius, Namibia, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. The Revised protocol on shared water courses (2000) signed by thirteen SADC member states in Namibia has been ratified by the two member states Botswana and Namibia.

Table 4 lists the principles for allocating shared waters of the SADC Shared Water course Systems Protocol (1995) in comparison with the Helsinki Rules on the Uses of the Waters of International Rivers (1966) and the UN Convention on Non-navigable Uses of International Watercourses (1997).

Data availability

References to data sources for the Southern African region as a whole are given in Table 8 in Section 5.1.

Table 4: Principles for Allocating Shared Waters (Sadoff et al., 2003).

Helsinki Rules on the Uses of the Waters of International Rivers (1966)	**SADC Shared Watercourse Systems Protocol (1995)**	**United Nations Convention on Non-navigable Uses of International Watercourses (1997)**
Within the meaning of Article IV a reasonable and equitable share is to be determined in the light of all relevant factors in each particular case.... Relevant factors which are to be considered include, but are not limited to:	*Utilization of a shared watercourse system in an equitable manner....requires taking into account all relevant factors and circumstances, including:*	*Utilization of an international watercourse in an equitable and reasonable manner requires taking into account all relevant factors and circumstances, including:*
1. The geography of the basin, including in particular the extent of the drainage area in the territory of each basin state	1. Geographical, hydrographical, hydrologic, climatical and other factors of a natural character	1 Geographic, hydrographic, hydrologic, climatic, ecological and other factors of a natural character
2. The hydrology of the basin, including in particular the contribution of water by each basin state	2. The social and economic needs of the member states concerned	2. The social and economic needs of the watercourse states concerned
3. The climate affecting the basin	3. The effects of the use of a shared watercourse system in one watercourse state on another watercourse state	3 The population dependent on the watercourse in each watercourse state
4. The past utilization of the waters of the basin, including in particular existing water utilization	4. Existing and potential uses of the shared watercourse system	4. The effects of the use or uses of the watercourses in one watercourse state on other watercourse states
5. The economic and social needs of each basin state	5. Guidelines and agreed standards to be adopted	5. Existing and potential uses of the watercourse
6. The population dependent on the waters of the basin in each basin state		6. Conservation, protection, development, and economy of use of the water resources of the watercourse and the costs of measures taken to that effect
7. The comparative costs of alternative of satisfying the economic and social needs of each basin state		7 The availability of alternatives, of comparable value, to a particular planned or existing use
8. The availability of other resources		
9. The avoidance of unnecessary waste in the utilization of waters of the basin		
10. The practicability of compensation to one or more of the co-basin states as a means of adjusting conflicts among uses		
11. The degree to which the needs of a basin state may be satisfied, without causing substantial injury to a co-basin state		

3.1.4 Water Scarcity – A Cross-Cutting Vulnerability Indicator

Water scarcity can be expressed as the ratio between water demand (or water withdrawal) and water availability. A threshold of 0.4 for this ratio is often taken as indicator for severe water scarcity. Figure 8 from Vörösmarty et al. (2000) shows the number of inhabitants per 0.5 degree pixel living above or below this threshold. The figure suggests that the Southern African region is currently at risk.

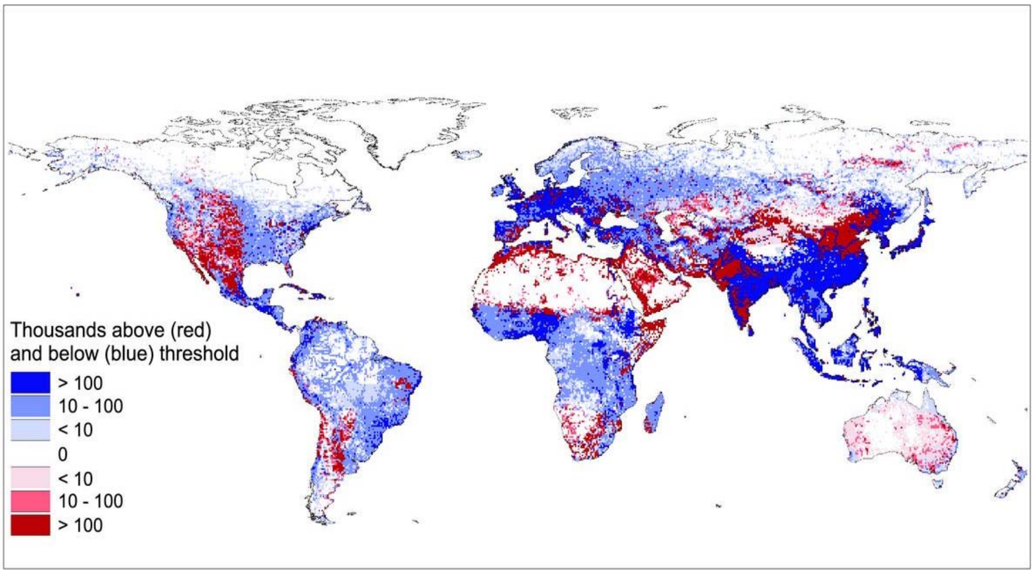


Figure 8: Population relative to water stress threshold (Vorosmarty et al., 2000).

SADC's population is expected to grow by about 50% by 2020 and 100% by 2050 (UN World Population Prospect) hence the water requirement for food supply will grow accordingly. Climate change may further aggravate the situation through decreasing water availability. The UN-WWDR (2003) suggests that climate change will account for about 20% of the increase in global water scarcity. Southern Africa is among the few regions in the world for which most global climate models (GCMs) agree upon further increase in aridity. Figure 9 compares the results of two GCMs – red areas are those where both models agree that precipitation will decrease. The combined effect of decreasing rainfall and increasing temperature as predicted for large parts of the region would lower the average water availability for livelihoods (DWC, 2003).

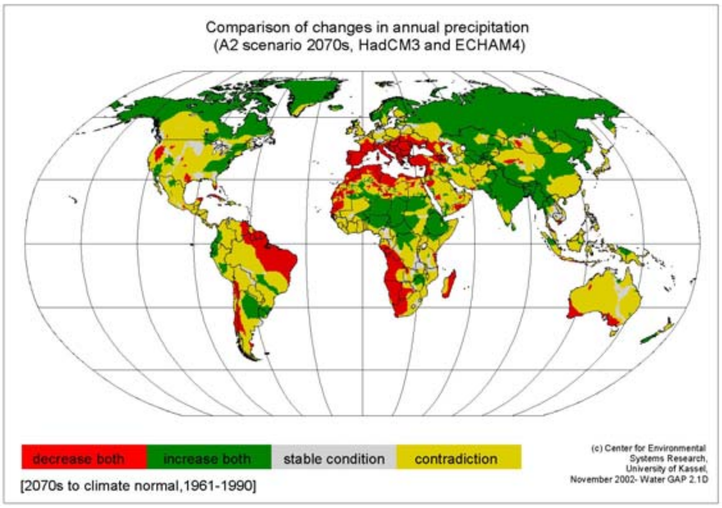


Figure 9: Comparison of two precipitation scenarios for 2070 (Alcamo et al., 2002).

Figure 10 depicts the change in water stress (ratios of water withdrawal to water availability in drainage basins) on a global scale between 1995 and 2025. Based on the above figures, Southern Africa, with its spatially and temporally highly variable water resources, is therefore not only currently but also in the future experiencing increasing water scarcity.

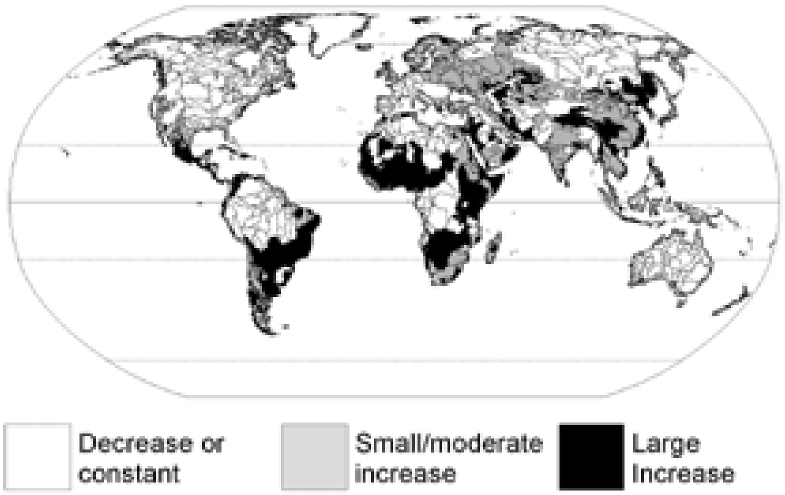


Figure 10: Changes in Water Stress between 1995 and 2025 under the World Water Vision's Business-as-Usual Scenario (Alcamo et al., 2000).

Alcamo and Heinrichs (2002) determined critical regions of water stress vulnerability up to the 2020s based on a comparison of the change in water withdrawals caused by changes in population, economic growth and technological change with the change in water availability due to climate change. From their study it can be deduced that most of the Orange and Limpopo River Basins are in a critical state and when combined these basins comprise one of the three largest critical areas in Africa. South Africa in particular is among the most severely water stressed countries in the world. Water scarcity will undoubtedly place a major constraint on food production, human health, and environmental quality. On top of water stress are the extreme events as shown in Figure 11. Here a web-based, timely early warning system for weather hazards (droughts and floods) for the whole of Africa illustrates areas at risk.

3.1.5 Southern African Vulnerability studies

To date, most Southern African vulnerability studies carried out have focused on drought vulnerability and the impact of climate change on water resources.

Southern Africa is among the world's most drought prone regions. 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 in the region. In many areas groundwater use is being increased in an attempt to limit the impact of rainfall scarcity and variability on agriculture. This and the fact that groundwater can be a safe, cheap and reliable source of water for domestic supply, is resulting in an increased reliance upon groundwater throughout Southern Africa.

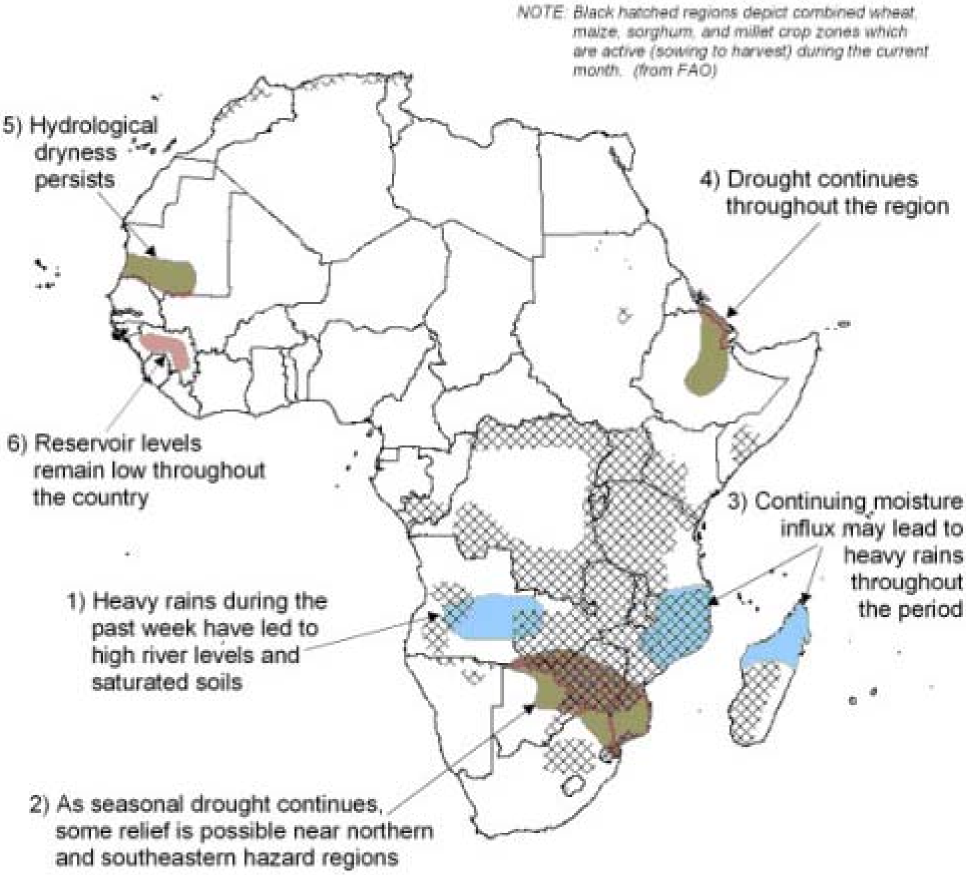


Figure 11: Web-based early warning for potential weather hazards (6-12 February 2003).

Source
Relief Web http://www.reliefweb.int/w/map.nsf/home?OpenForm

When the rains stop, and surface water sources dry up, groundwater can become the only water source available. As a result boreholes and wells that were previously utilised within a sustainable level are typically over-used at a time of diminished recharge. As a result water levels drop. The extent of aquifer depletion in such a situation is controlled by the aquifer's permeability and aquifer depletion may be either local or regional.

Among the advantages of groundwater use is its ability to buffer rainfall variability. Aquifers have significantly more storage capacity than surface water resources, and typically account for around 90% of water stored in a catchment.

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

- Hulme (ed), (1996): Focused on annual surface water runoff in the SADC region at 0.5° resolution.
- Meigh et al. (1998): An assessment of water availability in East and Southern Africa at 0.5° resolution. Included a demand/supply study incorporating both surface and groundwater.

- Schulze and Perks (2000): Detailed modelling exercises covering South Africa, Lesotho and Swaziland at 0.25° cell resolution, and applied to the 1946 Quaternary catchments.
- Vörösmarty and Moore (1991): On the hydrology and runoff of the Zambezi basin.
- Cambula, (1999): On the impact of climate change on the water resources of Mozambique.
- Cavé et al. (2003). Impact of climate change on groundwater recharge estimation.

Recharge is one of the critical parameters in determining water availability. Changes in recharge will result from changes in effective rainfall as well as a change in the timing of the rainfall season (Gleik, 2000). In general, under a scenario of global warming, increasing temperature results in decreasing precipitation over the central continental areas causing decreasing recharge and thus depletion of groundwater resources. Indirect impacts on groundwater resources may also arise from climate change impacts on vegetation and human activities e.g. groundwater abstraction patterns. Rainfall – recharge relationships may be used in a first attempt to assess impacts of climate change on groundwater resources (Cavé et al., 2003).

In the following sections rapid assessments will be made of the two largest Southern African River Basins south of the Congo River Basin: the Zambezi and the Orange River Basins.

3.2 Zambezi River Basin

South of the Congo River Basin, the Zambezi is the largest river basin in Southern Africa. 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 12).

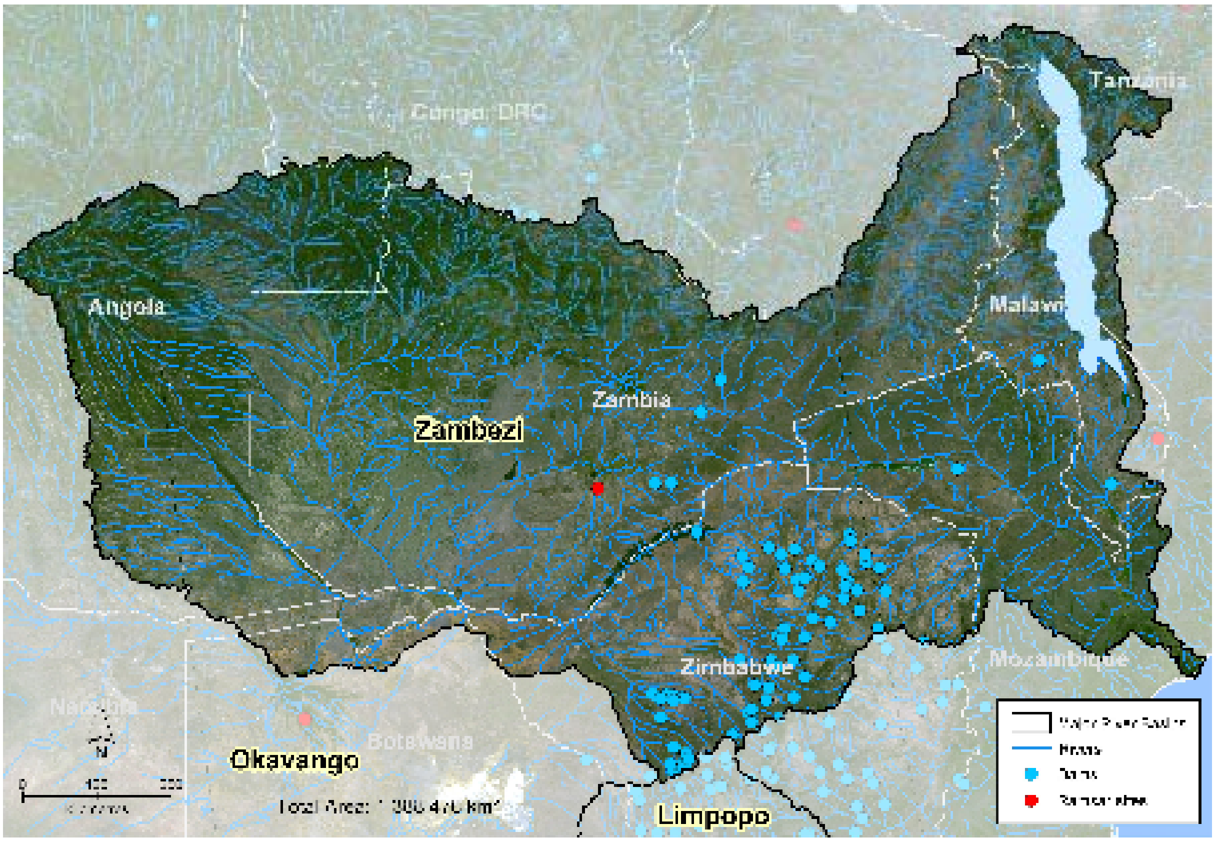


Figure 12: Zambezi River Basin.

Source	
Satellite Image:	USGS MODIS, 28 December, 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 basin are floodplains, swamps, lakes and dams. Box 1 summarizes the main characteristics of the basin. Over 30 large dams have been built in the Basin with an estimated total capacity of 221 000 Mm^3. Water resources of the basin are still sufficient at present to meet human demands but this situation is expected to deteriorate with population growth. The most significant increase in water consumption will most probably be for large-scale irrigation projects.

3.2.1 Physiography

Climate

Most rainfall occurs during the summer season between October and April. Rainfall in the basin averages 990mm 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

Box 1: Zambezi River Basin – Main characteristics.

Basin

Surface area: 1 388 000 km^2

MAP: 700 – 1 200 mm/a

Demography

Population: 25.4 million

Density: 18 persons/km^2

Water Resources

River length: 2 650 km

MAR: 94 000 Mm^3/a

Major dams

Kariba: 160 000 Mm^3

Cahorra Bassa: 52 000 Mm^3

Itezhitezi : 5 600 Mm^3

Total dam storage: 221 245 Mm^3

Major Aquifers: crystalline basement

Water Use

Agriculture
Domestic
Industry
Mining
Hydroelectric

Increasing

Vulnerability

Increasing to the East

Source

Pallett, 1997; Seyam, 1999; Hirji et al., 2002

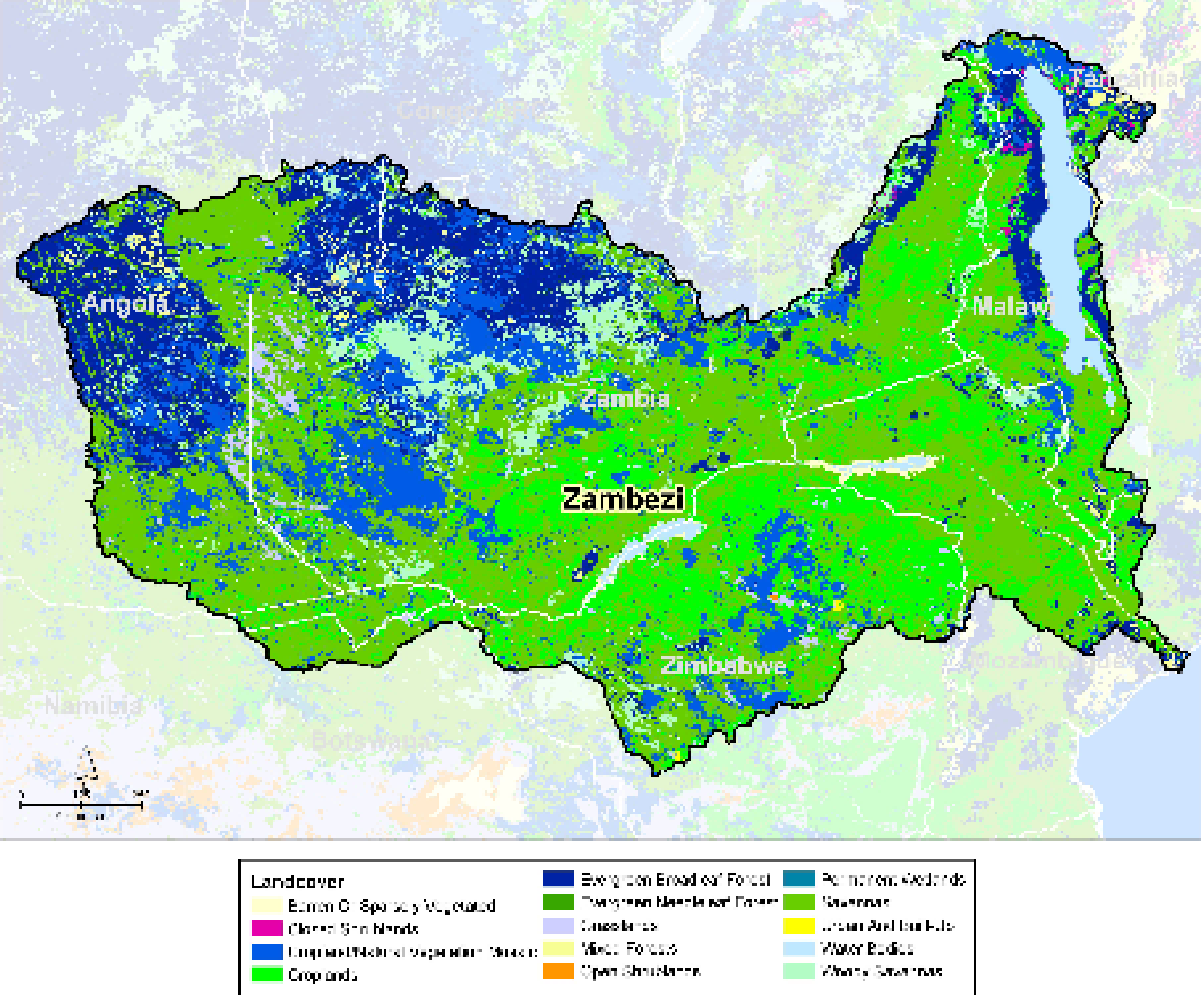
of 1200 mm, while the southern and south-western parts receive 700 mm. Average annual actual evapotranspiration is 870 mm; it ranges from 1000 mm in the Luangwa, Shire and lower parts of the basin to 500 mm in the south-western parts of the basin (Savenije and van der Zaag, 1998).

Ecosystems

There is only one Ramsar protected wetland in the Zambezi River Basin (Kafue Flats). National parks, game reserves, and safari areas 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 7 are intruder 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 under threat of extinction. Three bird species are endemic to the basin.

Figure 13 shows the landcover of the basin. Savannas cover almost half the total land area. 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%). These are however largely restricted to the Angolan and northern Zambian parts of the basin. At least 20% of the basin area is under crop cultivation. This is likely to increase as a result of population growth and the integration of Africa into global trade.



Description	Percentage
Barren Or Sparsely Vegetated	1
Closed Shrublands	0
Cropland/Natural Vegetation Mosaic	15
Croplands	19
Evergreen Broadleaf Forest	14
Grasslands	1
Mixed Forests	1
Open Shrublands	0
Permanent Wetlands	0
Savannas	41
Urban And Built-Up	0
Water Bodies	3
Woody Savannas	6

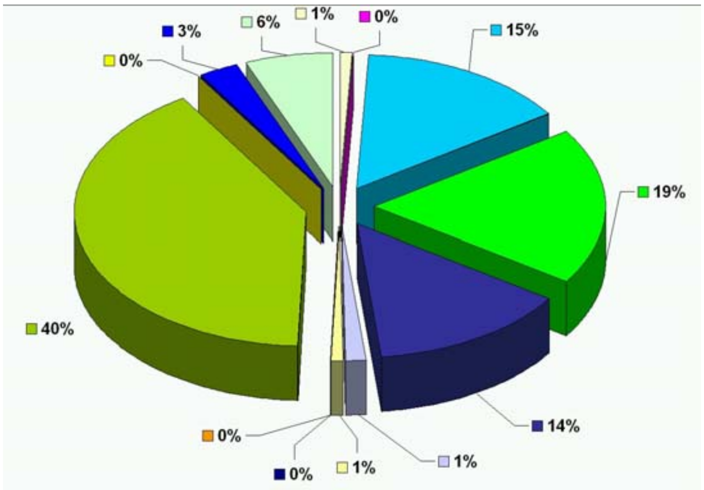


Figure 13: Landcover Zambezi River Basin (IGBP Legend).

Source
USGS Africa Landcover Characteristics Data Base (2003) - http://edcdaac.usgs.gov/glcc/glcc.html

Hydrology

The volume of annual renewable water resources in the Zambezi River is estimated at 3600 m^3/s or 87 mm of equivalent rainfall, which is just under 10% of the average rainfall in the basin (Table 5; Savenije and van der Zaag, 1998). The figures for flow during the wet and dry seasons serve as a useful overview of seasonal flow variation.

Table 5: Runoff of Zambezi River and its Main Tributaries (m^3/s). (Savenije and van der Zaag, 1998).

Tributary	Annual	Wet Season	Dry Season	Catchment Area (km^2)
Zambezi River at sea	3600	5000	1500	1,300,000
Shire River Basin	500	550	360	150,000
Luangwa River Basin	620	1500	90	144,000
Kafue River basin	350	450	100	152,000
Kambopo River Basin	260	400	120	37,000
Zambezi River at Kariba	1350	1500	900	664,000
Zambezi River in Angola	670	900	150	76,000

The tributaries of Chobe/Cuando, Luenginga and Lungue Bunguo, Gwayi and Sanyati rivers occupy large portions of the Zambezi River Basin, but make little contributions to its flows compared to those listed in Table 5.

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 hydro-electrical 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 for the foreseeable future.

Hydrogeology

The basin is predominantly underlain by basement rocks (Figure 14). Wells located in fractured or weathered zones may be moderate to high yielding (1 – 5 m^3hr^{-1}). Groundwater from these areas is generally of 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 with depth. This variability is usually a reflection of locally complex groundwater flow regimes (UN, 1988; Botha, et al., 1998).

3.2.2 Socio-Economy

Demography

Population figures from 1994 indicate that there are just over 25 million people living in the Zambezi Basin (Seyam, 1999). This would translate in an average population density of 18 people per square kilometre. Table 6 shows the population size in the Zambezi Basin per basin country. Ten large urban centres with populations > 100 000 are found in the basin. The present rate of growth of urban centres is estimated at 5% (Revenga et al., 2000).

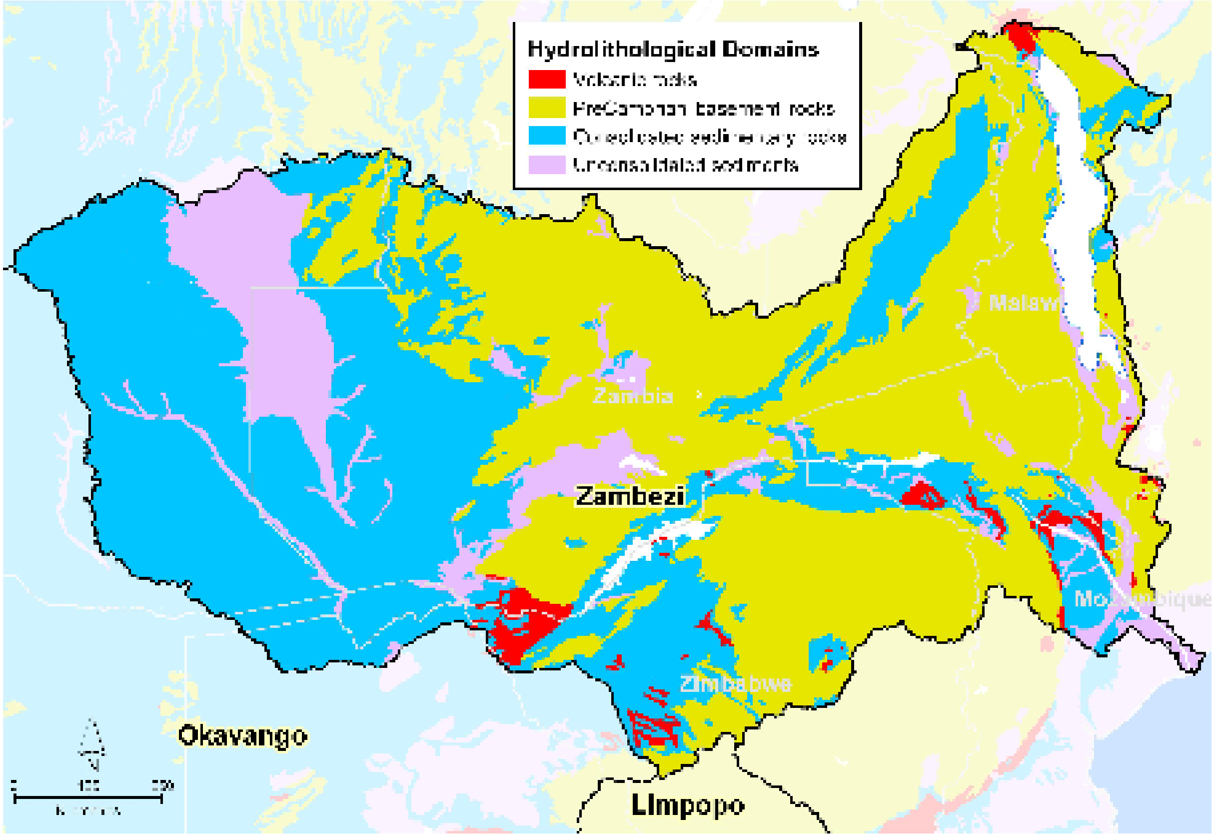


Figure 14: Hydrolithological Domains Zambezi River Basin.

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

Table 6: Population of Zambezi River Basin countries in 1994 (Seyam, 1999).

Country	**In-basin Population (millions)**
Angola	0.4
Botswana	0.0
Malawi	8.4
Mozambique	2.2
Namibia	0.1
Tanzania	0.6
Zambia	7.3
Zimbabwe	6.5
Total	**25.4**

Economy

The Zambezi River and its tributaries are vital to the livelihood of more than 25 million people who derive benefits from its water, hydroelectric power, irrigation developments, fisheries and a wealth of natural resources (Pallett, 1997).

Over 30 large dams in the Zambezi River basin serve domestic, industrial and mining water supply, irrigation and power generation. The estimated hydropower potential of the Zambezi Basin is 20000 MW, of which about 4500 MW has been installed to date (Pallett, 1997).

The main focus of economic activity in the Zambezi Basin is on agriculture and mining. The region is largely under-developed, with high unemployment and widespread poverty. Main agricultural products include corn, sorghum and rice, while mining concentrates on copper deposits.

Tourist revenue attracted by the natural beauty of the Zambezi River Basin makes significant contributions to the economies of the basin countries. At the same time the ecosystems of the Zambezi River provide a wide range of natural resources (including fisheries and forestry) that support local populations.

3.2.3 Management

Legislation and Institutional Framework

The majority of the Basin population lives in Malawi, Zambia and Zimbabwe. Of these countries, Zimbabwe has only recently (1998) changed its water legislation and institutional framework to a holistic approach to water resource management. In Zambia, legislative and institutional reform is currently underway (http://www.zambia-water.org.zm/wrap.htm).

Zimbabwe water legislation and institutional framework

Main legislation regarding water resources development and management in Zimbabwe relates to the Water Act (1998) and the associated regulations. The aim of the new Act is to improve the equity and access to water by all stakeholders and the effective and sustainable management of water resources by stakeholders. Major changes in comparison with the old (1976) Act are:

- water rights are abolished and water permits of a fixed duration introduced. The permits are subject to review and renewal,
- groundwater elevated to the same status as surface water and the two are now jointly referred to as water resources hence effectively removing the perception of private water (water now vested in the State). The concept of the Hydrologic Cycle is fully recognised,
- priority date system in issuing water in times of scarcity discarded,
- the environment is appreciated as a rightful user of water,
- pollution now attracts heavy fines,
- administration of the Act less cumbersome,
- water resources management devolved to stakeholders through the formation of Catchment Councils and Sub-Catchment Councils which are technically and professionally backed by Catchment Manager's Offices.

Associated regulations such as the Water (Permit) Regulations (2001) provide a legal framework for both surface water and groundwater development, use and management. Water (waste and effluent disposal) regulations (2000) provide a legal framework for water quality issues and also provide the guidelines and concepts for water quality monitoring.

Administration and management of the Water Act (1998) required the establishment of bodies outside the government. This saw the formation of the Zimbabwe National Water Authority (ZINWA) in 2000 and Catchment Councils and Sub-catchment councils with specific roles and responsibilities.

River Basin Management

In the mid 1980s riparian states formulated and adopted the Zambezi River Basin Action Plan (ZACPLAN) to establish mechanisms for common management of the Zambezi River (Shela, 1998). Unfortunately, only few of the 19 envisaged projects of the Action Plan have since been financed and implemented. One of the projects: the establishment of a basin treaty for common management became redundant by the development of the SADC Protocol on Shared Watercourse Systems in 1995. The setting up of a competent basin institution and capacity building inside the basin for co-ordination and implementation of ZACPLAN was not pursued. The institutional weaknesses and lack of budget provisions are likely to blame for the failures of water resources management programmes as well as the slow progress in the implementation of ZACPLAN (Shela, 1998). According to Hirji et al. (2002), the success of ZACPLAN will only be realized when an institutional framework with a mandate over the whole basin and political backing of the basin states has been adopted. Bilateral agreements between basin states (such as for instance between Zambia and Zimbabwe: Zambezi River Authority) and major water related projects need to be adequately integrated into the management strategy and adopted by the basin states. They further recommend that the database ZACBASE should be operationalised by linking it to real-time data sources and utilized to provide alternative large-scale development and management scenarios for the basin.

Data availability

References to data sources for the Zambezi River Basin and the riparian countries are given in Table 8 in Section 5.1.

3.3 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. The remainder falls within Botswana (13%) and Namibia (25%), completely encapsulating Lesotho (2%; Figure 15).

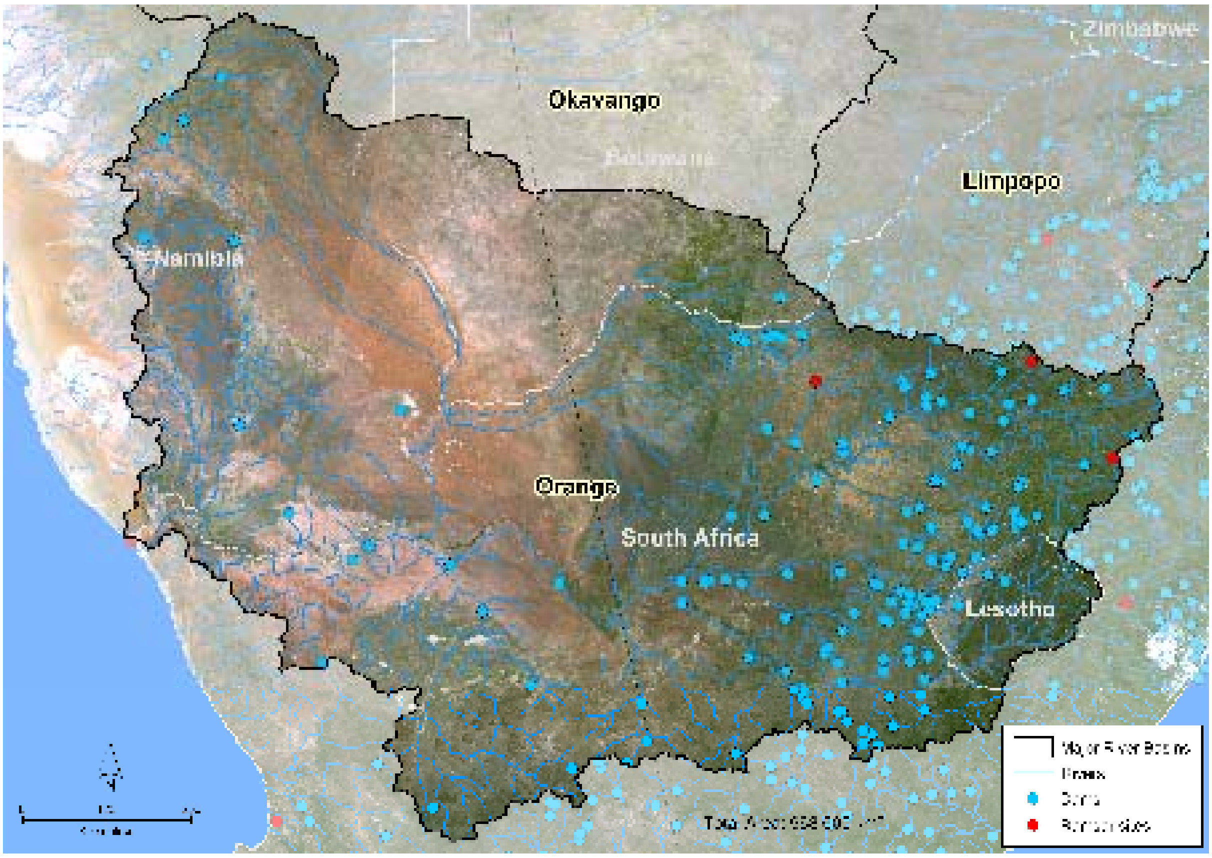


Figure 15: Orange River Basin.

Source

Satellite Image:	USGS MODIS, 28 December, 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 basin, their role in the watercourse is less significant due to the fact that the nearest point of the Botswana border is 200km away from the river and very little input is gained from the Fish River in Namibia except from floods. The Orange River originates in the Lesotho Highlands in the east and drains into the Atlantic Ocean in the west. Box 2 summarizes the main characteristics of the basin.

3.3.1 Physiography

Climate

The mean annual rainfall for the basin is about 400mm per year, with a high degree of variability from approximately 2000mm 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 mouth.

Box 2: Orange River Basin – Main characteristics.

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

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

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

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

Water Use
Agriculture
Domestic
Industry
Mining
Hydroelectric
↑ **Increasing**

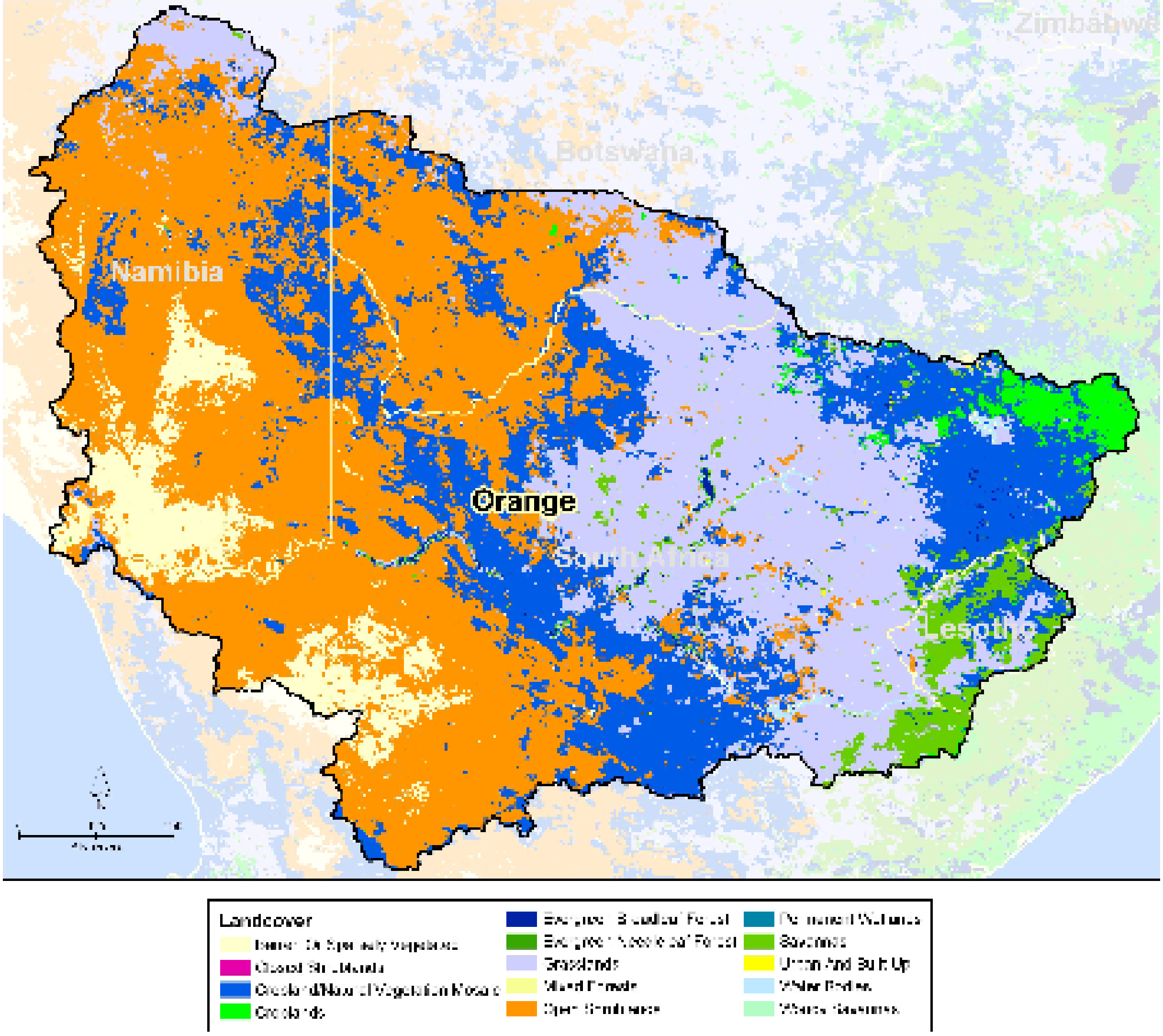
Vulnerability
Increasing aridity to the west

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

Ecosystems
The landcover and ecology of the Orange River Basin reflect the large variation in precipitation and change in elevation that is found in the basin. The largest part of the basin is (semi-)arid (see Figure 4), which limits agricultural activity in most of the basin to livestock husbandry. An analysis of Landsat imagery shows that grassland and shrubland dominate the landcover in the basin.

Among the more valued natural resources in the 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 7 are endemic, two of which are threatened by extinction. Two endemic bird species occur in the basin.

Figure 16 shows the change in landcover with increasing aridity from east to west from cropland/natural vegetation and grasslands (46%) to open shrublands (42%) and barren/sparsely vegetated soils (6%).



Description	Percentage
Barren Or Sparsely Vegetated	6
Cropland/Natural Vegetation Mosaic	23
Croplands	2
Evergreen Broadleaf Forest	0
Grasslands	23
Open Shrublands	42
Savannas	3
Urban And Built-Up	0
Water Bodies	0
Woody Savannas	0

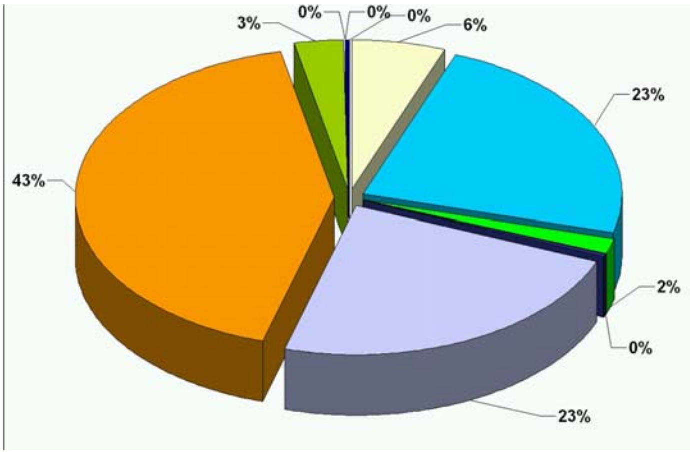


Figure 16: Landcover Orange River Basin (IGBP Legend).

Source
USGS Africa Landcover Characteristics Data Base (2003) - http://edcdaac.usgs.gov/glcc/glcc.html

Hydrology

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 books of maps and data volumes at a quarternary catchment scale (Midgley et al., 1994):

- Quarternary and tertiary catchment information
- Rainfall, evaporation, streamflow (on a monthly basis)
- Landcover and water use
- Simulated natural streamflow
- Rainfall-runoff relationships
- Low-flow analysis, and
- Storage-yield

The data and map series cover a time span of 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 $m^3.a^{-1}$ and as little as 1 100 $m^3.a^{-1}$ due to climatic variations (Conley and Van Niekerk, 1998). Through a number of dams and transfer schemes, water is moved in and out of the Orange River. These include:

- The Orange River project: transfer of water from the Caledon and Orange Rivers to the Modder and Riet Rivers of the Eastern Cape,
- Tugela – Vaal Water project that transfer water from the Tugela River into the Vaal River to meet high water demand in the large industrial and population centres of the Gauteng Province of South Africa,
- The Orange-Fish tunnel project that supplements flow in the Fish and Sundays Rivers of the Eastern Cape (Pallett, 1997), and
- The Lesotho Higland Water scheme, that transfers water from the headwaters of the Orange River to the Vaal River (http://www.sametsi.com/).

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. The large number of dams and transfer schemes in the Orange River basin controls flow and mitigate the occurrence of flood and drought events. Climate change may however result in increased precipitation variability and a resultant increased frequency in flood and drought events.

Hydrogeology

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 17). 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 hydrogeological information can be obtained from the following maps (Vegter, 1995; 2001):

- Borehole Prospects (1: 2,500,000)
- Saturated Interstices - a qualitative indication of groundwater storage (1: 4,000,000)
- Depth to groundwater level (1:7,500,000)
- Mean annual groundwater recharge (1:7,500,000)
- Groundwater component of river flow (1:7,500,000)
- Groundwater quality (1:7,500,000) and
- Hydrochemical types (1:7,500,000)

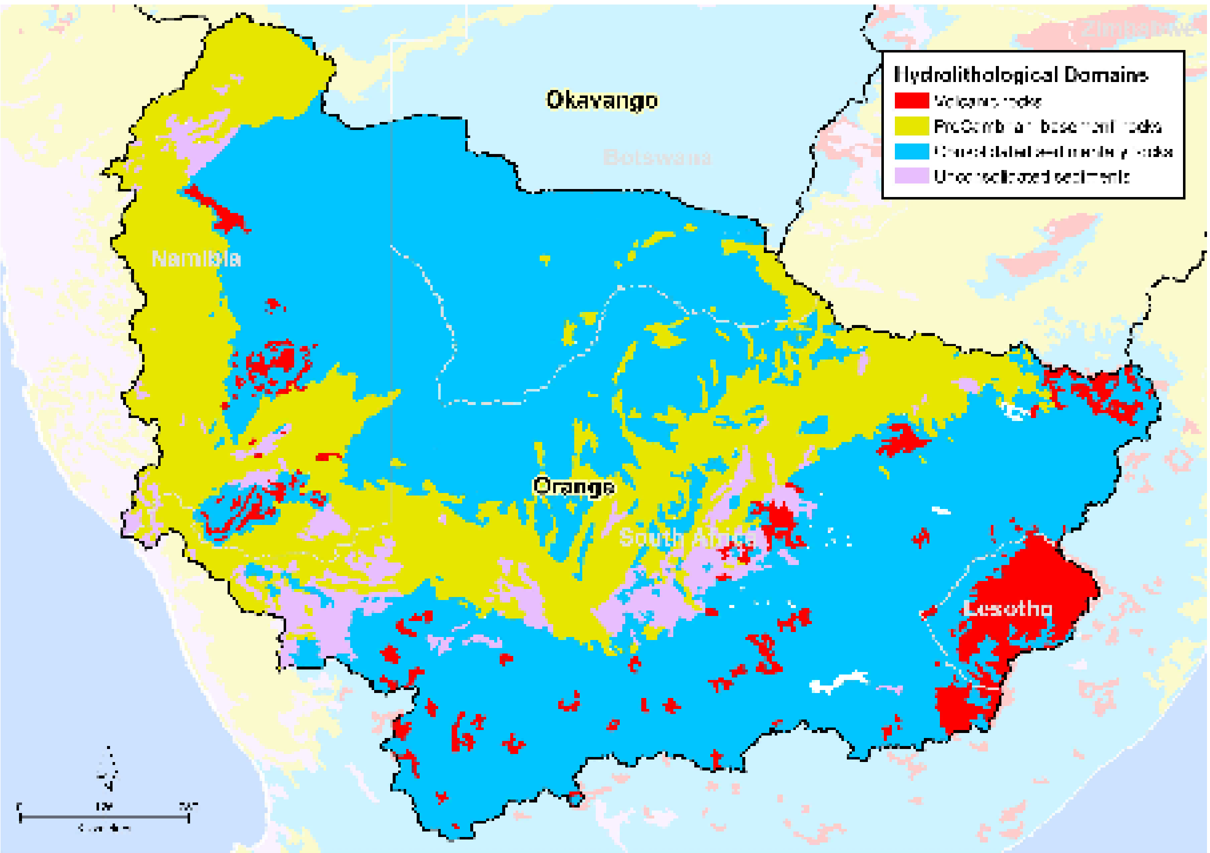


Figure 17: Hydrolithological Domains Orange River Basin.

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

The maps depict groundwater conditions on a regional scale. In 1996 the Department of Water Affairs and Forestry (DWAF) of South Africa published the harvest potential map (1:3,000,00). This map was the first attempt to produce a national coverage on the maximum volume of groundwater per km^2 per year that may be abstracted without depleting the aquifer. It is based on recharge and groundwater storage. A second phase of DWAF's groundwater resources assessment programme, which aims at greater detail is underway.

Groundwater exploration is presently focussed on the location and development of:

- Zones of dolerite intrusions and their hardened contact zones in the Karroo sediments. Yields vary, but is generally less than 4 m^3/hr (Botha et al.,1998). The value of this aquifer is that it occurs in the semi-arid interior of the region where little other sources of water are available.
- Cavities in the Karstic dolomite and limestone deposits. In places these caverns are traversed by veins of dolerites and syenites, which divide 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.

- Beds of higher permeability in the Kalahari sand succession. In parts of the Kalahari, groundwater quality is poor, and in places it may be too saline for use (UN, 1988).

Groundwater use in the basin largely serves agricultural demand (livestock watering) and water supply to rural towns and villages. Water quality in the Karoo succession is often poor. Sophisticated (geophysical) exploration methods are often required in order to locate aquifers associated with fracture systems, relatively thin sandstone layers and igneous intrusions.

Groundwater recharge is one of the critical parameters in determining water availability and when related to water use also in determining water scarcity (see Section 3.1). Figure 18 depicts the mean annual recharge (mm) for the Orange River Basin. The map is a composite of Vegter's provisional recharge map of South Africa (1995) and the recharge map which was 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 (e.g. Gieske, 1992; Bredenkamp et al., 1995; Beekman et al., 1996; 1999; Xu and Beekman, 2003), much more work is needed before coverages can be produced that depict spatial and temporal variability in recharge reliably 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 then in terms of mean annual rates.

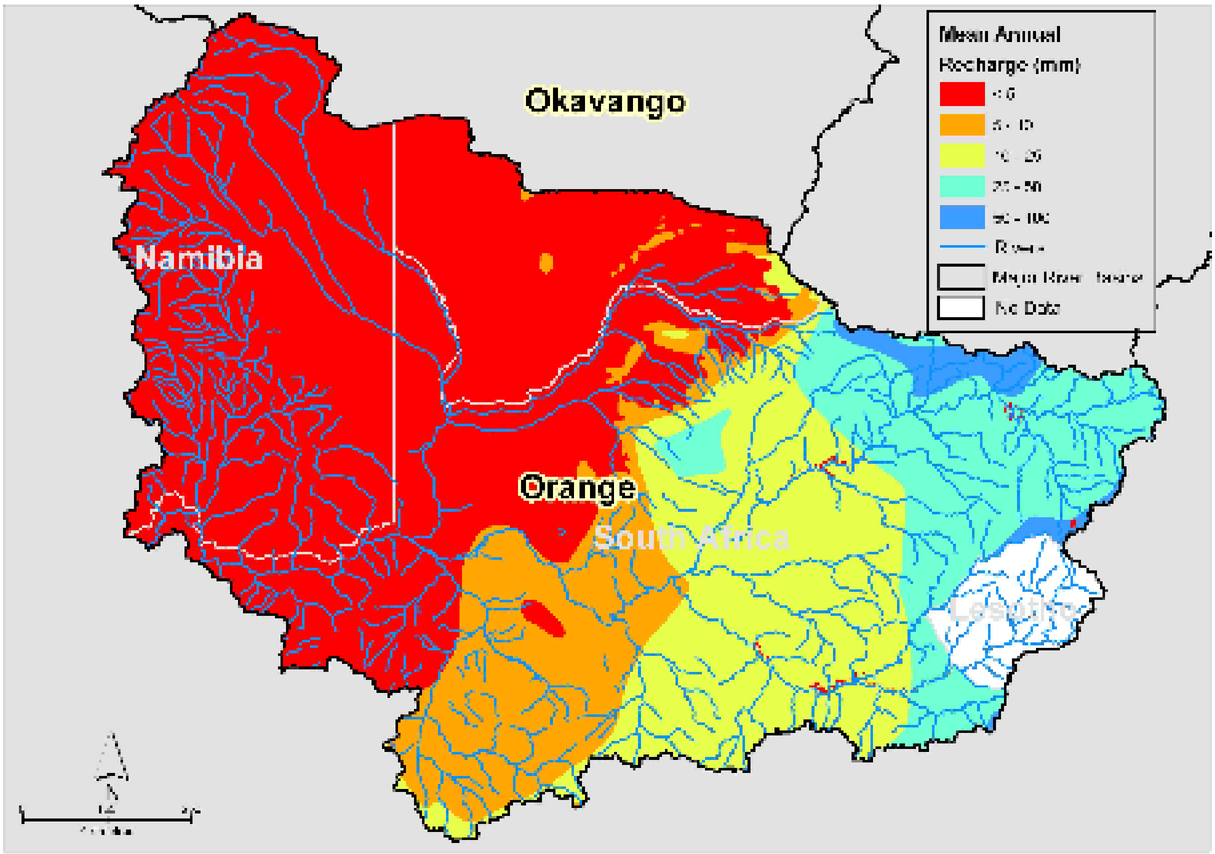


Figure 18: Mean annual groundwater recharge in the Orange River Basin.

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

3.3.2 Socio-Economy

Demography

The large industrial conurbation in the Gauteng Province of South Africa dominates the population distribution of the Orange River Basin. The lure of apparent opportunity and wealth has resulted in an urban growth rate of 4.6%. The northern and western parts of the basin are sparsely populated. The Orange River basin is home to over 11 000 000 people, with an average population density of 12 people per square kilometre.

Economy

Economic activity in the Orange River basin is dominated by industrial and mining activity in the Gauteng province. The highly developed economy of this province contributes close to 40% to the GDP of South Africa. Important economic sectors include mining, manufacturing and services. Much of the dam construction in the basin is geared towards meeting the water demands of the Gauteng Province.

3.3.3 Management

Legislation and Institutional Framework

South Africa plays a key role in the management of water resources within the Orange River Basin. Note that the majority of the Basin population lives in South Africa. South African water resources are governed by the Water Services Act of 1997 and the National Water Act of 1998.. The Acts are complementary to each other; they serve to provide the framework for sustainable water resources 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 integrated water resources management (IWRM) approach is adopted which recognises the connection between water, land, human development and the natural environment. The Act serves to ensure that water resources are protected, developed, conserved, managed and controlled in order to:

- Meet the basic human needs of present and future generations;
- Promote equitable access to water;
- Redress the results of past racial and gender discrimination;
- Promote the efficient, sustainable and beneficial use of water in the public interest;
- Facilitate social and economic development;
- Provide for growing demand for water use;
- Protect aquatic and associated ecosystems and their biological diversity;
- Reduce and prevent pollution and degradation of water resources; and
- Meet international obligations.

To achieve this, the National Water Act (1998) requires the establishment of institutions with appropriate community and racial/gender representation. The catchment is recognised as the structural level at which local level participation can best be effected. This is inline with establishing institutions that are democratic, self-driven and require only limited State intervention.

Management of water resources under the National Water Act takes place both at national (Department of Water Affairs and Forestry), regional and local levels. At regional level the country is divided into 19 Water Management Areas. They will be managed through community-based Catchment Management Agencies. At local level water resources are managed by Water User Associations and Water Services Authorities.

Most important issues which the South African water sector should address according to Reed et al. (2003) are:

- Development of capacity at operational, strategy and policy levels: attention should be paid urgently to this;
- Equitable trans-boundary agreements. These should encompass shared local development, as well as social and economic objectives in order to avoid potential conflict and expedite planning and development in shared river basins;
- Planning for the impacts of climate change on water availability. This should be given more attention and should be underpinned by reliable scientific information; and
- Public-private partnerships between government and industry should be stimulated as they would help to support water resources management functions through provision of capacity and data.

Orange-Senqu River Commission

An agreement was signed in 2000 by the River Basin States Botswana, Lesotho, Namibia and South Africa to establish the Orange Senqu River Commission (ORASECOM), which serves to enable the development of the Orange River for the benefit of all in the respective basin States (www.namibian.com.na/2000/November/news/00B5F76236.html). It was the first of its kind since the Protocol on Shared Watercourse Systems became an instrument of international water law in the Southern African Development Community. The Commission will develop a comprehensive perspective of the Orange River Basin, study the present and planned future uses of the river system and determine the requirements for flow monitoring and flood management. It is expected to strengthen regional solidarity, contribute to peace and harmony and enhance socio-economic cooperation. The multi-lateral Orange-Senqu River Commission will not replace existing bilateral Commissions between any of the watercourse states but rather provide a broader forum for overall consultation and co-ordination between the watercourse states for sound, integrated water resources management and development in the Orange River basin. Despite all good intentions, the central problem of unequal access to water still remains essentially unsolved.

Data availability

References to data sources for the Orange River Basin and the riparian countries are given in Table 8 in Section 5.1.

4 SYNTHESIS

4.1 Comparison of Zambezi and Orange River Basins

In Table 7 a brief summary is given of main aspects of water resource vulnerability for the Zambezi and Orange River Basins and grouped into the physiographic, socio-economic and management clusters.

Table 7: Water Resource Vulnerability 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 p/km^2; downstream increase; variable	12 p/km^2; upstream increase; variable
	Access to Safe Water	Urban ~70%, Rural ~45%; highly variable	Urban ~70%, Rural ~45%; variable
	Water Use	Agriculture ~80%	Agriculture ~60%
	Poverty	Higher	Lower
	Conflicts	Eastern Caprivi region	Lower Orange River
Management	**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 as occurred during the early 1990s caused temporary conditions of increased aridity.
- Water availability is particularly critical for the Orange River Basin. Climate change and climate variability for the coming years 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 with the Zambezi River Basin, with many dams and transfer schemes in the upstream regions, but the total storage of its major dams is a tenfold less.

Socio-Economy

- Some projections (UN World Population Prospect) foresee a doubling of SADCs population by 2050 but this is likely to be less due to the spread and impact of HIV/AIDS.
- The combination of population growth (though 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 (CIA, 2000; Ashton and Ramasar, 2002). The figures given in Table 7 are averaged values and are merely indicative. Differences between nations in terms of access to safe water and sanitation are more pronounced for the

Zambezi River Basin case. About one third of the total SADC population live in formal urban areas.

- The Gross Domestic Product (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 as a per capita GDP or as a Human Development Index (HDI), poverty is more prevalent for the Zambezi River Basin than for the Orange River Basin.
- Agricultural water use dominates in most Southern African countries when compared to the domestic and industrial water use sectors: ~80% of the total use for the Zambezi River Basin and ~60% for the Orange River Basin (WRI, 2000; Ashton and Ramasar, 2002).
- Many of the water related conflicts in Southern Africa that occurred in the past are likely to continue in the future as a result of escalating demands and pressures that continue to be placed on its finite and scarce water resources (Ashton, 2000). The degree of international conflicts, however, is expected to be limited. Ashton (2000) 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 conflict in Southern Africa are the Eastern Caprivi region bordered by Botswana, Namibia and Zambia (ownership of islands) and the lower reaches of the Orange River bordered by Namibia and South Africa (territorial and water-related rights; Ashton, 2000).

Management

- Water Sector Reforms are in progress 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 with its reforms and implementation. On a river basin level an agreement was signed in November 2000 by the 4 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 water 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 demands and withdrawals for agricultural use, this river basin is among the most severe, water scarce, regions in Africa. Future projections of the various physiographic, socio-economic and management parameters suggest a further aggravation of the situation, that is if there would be no appropriate human intervention. The same holds true for the Zambezi River Basin although water availability seems to be less critical at the moment.

4.2 Virtual Water Trade - An adaptation mechanism for water stress

The concept of Virtual Water (VW), defined as the amounts of water used to grow crops (virtually embodied in the crops) and traded internationally (Allan, 1996), is currently gaining momentum (see e.g. Hoekstra, 2003; Meissner, 2003). The concept has the potential to be used as an element of an adaptation strategy regarding present and future water scarcity and thus food-insecurity amongst others resulting from global change. Trading in VW (VWT) can therefore be an instrument in solving geopolitical problems and preventing conflicts over water. Ideally this relatively new concept should form a basis for drafting water policy plans, both at local, national and regional (transboundary) levels.

Status of Virtual Water in Southern Africa

The level of trade in virtual water between the states in Southern Africa is very low, despite the contrast between high levels of water stress experienced in some countries (e.g. Botswana and South Africa) and the abundance of water available in other countries (e.g. Zambia; Earle and Turton, 2003). The amount of virtual water entering the region – mostly from overseas - was estimated at $8*10^9$ m^3 in 2002 (about 1 m^3 for each kg of grain) and is far greater than the amount of water physically transferred through large-scale water transfer schemes between the SADC states, which amounts to about $5*10^9$ m^3 (Heyns, 2002). Earle and Turton (2003) suggest that the current low level of Virtual Water Trade (VWT) has much to do with political instability and a lack of second order resources (institutional, economic and human capital) in water-rich countries that potentially could export virtual water. They propose that investing in the grain production and transportation infrastructure of the well-watered, but less developed SADC states by the richer states, is more sustainable and viable than building new large water transfer schemes. According to Meissner (2003), a VWT strategy is, under the current environmental, political and economical conditions not possible for many SADC countries. Meissner (2003) emphasized, however, that further research into the concept of virtual water is justified as its power lies within its ability to assist in increasing food security without compromising water security.

5. REFERENCES AND DATA SOURCES

5.1 Africa / Southern Africa

Results of an inventory of data availability at regional and national scales are shown in Table 8. References (numbers in the table) are grouped according to the main vulnerability assessment clusters and sub-clusters (see Section 2.3).

Table 8: Data availability for the vulnerability assessments in Southern Africa.

	PHYSIOGRAPHY								SOCIO-ECONOMY			MANAGEMENT					
COUNTRY / REGIONAL	Climate	Climate Change and Impacts	Ecosystems		Hydrology		Hydrogeology		Sociology - Health	Hydro-politics	Economy	Legislation, regulations and guidelines		Water Sector Reform – IWRM	Water Master Plan	Data-bases and Maps	Digital Coverage
Angola	1 2 3 4	1 2 3 4 5 6 7 8 9 10 11 12 13 14		1 3 5 9 11 13 14 15 18		1 2 3 6 8 12 13 16		5 6 13 14 15 21 22	6 7 9 11 13 19 20 21 24 26 27	1 2 4 5 10 12 13 14 15 16 18 25	1 2 3 8 9 12 13 14 15 16 17 18 19 22 23 26		34 35	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	1	1	1 2 3 4 5 6 7 8 9 10 11
Botswana							1 2 7 11 12								2		
Lesotho			2 20		17		19					1					
Malawi			8									2 3 4			3		
Mozambique					5							5			4		
Namibia							8 9 20					6 7 8			5		
South Africa			4 6 12		4 10 13 14 15 18		3 4 16 17 18 19					9 10 11 12 13 14 15 16 17 18 19			6		
Swaziland			16		9		19					20					
Zambia			7 17		7							21 22 23 24 25			7 8 9		
Zimbabwe			10 19		11		10					26 27 28 29 30 31 32 33			10 11		

🟨 Africa / Southern Africa

☐ Country-specific

Physiography

Climate

1. Corbett, J.D., and Kruska, R.L. 1994. Africa Monthly Climate Surfaces, v1.0. Three arc-min resolution. Based on climate coefficients from CRES, Canberra, Australia. Data for mean long term normal minimum temperature, maximum temperature, and precipitation. ICRAF/ILRAD, Nairobi, Kenya. (CD-ROM publication).
2. Corbett, J.D. 1995. Monthly evapotranspiration surfaces for Africa, v1.1. Climate coefficients created using ANUSPLIN (CRES, ANU, Canberra), ICRAF, Nairobi, Kenya (CD-ROM publication).
3. Matsumoto, J. 1993. Global distribution of daily maximum precipitation, Bull. Of the Depart. of Geography, Univers. of Tokyo, pp. 25.
4. Preston-Whyte, R.A. and Tyson, P.D. 1988. The atmosphere and weather of Southern Africa. Oxford University Press, Cape Town.

Climate Change and Impacts

1. Cambula, F. 1999. Impacts of climate change on water resources of Mozambique: Final report of the Mozambique/US Country Study, National Environment Commission, Maputo.
2. Cavé, L., Beekman, H.E. and Weaver, J. 2003. Impact of climate change on groundwater recharge estimation. In “Groundwater recharge estimation in Southern Africa” Xu, Y. and Beekman, H.E. (eds), UNESCO IHP Series No. 64.
3. Gustard, A. and Cole, G. 2002. FRIEND – a global perspective 1998 – 2002. Centre for Ecology and Hydrology, Wallingford, U.K. ISBN: 1-903741-03-3.
4. Hulme, M. (ed) 1996. Climate change and southern Africa: An explanation of some potential impacts and implications in the SADC region. A report commissioned by WWF International and co-ordinated by the Climatic Research Unit, UEA: Norwich.
5. IUCN. 1999. Climate Change in southern Africa, Workshop report.
6. Jones, P. and Thornton, P. 2003. The potential impacts of climate change on maize production in Africa and Latin America in 2055, Global Environmental Change 13, pp 51–59.
7. Meigh, J. R., McKenzie, A. A., Austin, B. N., Bradford, R. B., and Reynard, N. S. 1998. Assessment of global water resources – Phase II: Estimates for present and future water availability for eastern and southern Africa, DFID Report No. 98/4, Institute of Hydrology, Wallingford, Oxon.
8. Rowlands, I.H. (ed) 1998. Climate change cooperation in southern Africa. Earthscan and UNEP: London/Nairobi.
9. Schulze, R. E., and Perks, L. A. 2000. Assessment of the impact of climate change on hydrology and water resources in South Africa: Report to the South African Country Studies for Climate Change Programme, ACRUcons Report 33, School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pieternaritzburg.
10. Schulze, R. Meigh, J. and Horan, M. 2001. Present and potential future vulnerability of eastern and southern Africa’s hydrology and water resources, South African Journal of Science, 97, March/April 2001, pp150 – 160.
11. Tyson, P.D. 1986. Climatic changes and variability in southern Africa. Oxford University Press, Cape Town.
12. Van Jaarsveld, A. and Chown, S. 2001. Climate change and its impacts in South Africa, TRENDS in Ecology & Evolution Vol.16 No.1, pp 13 – 14.

13. Vörösmarty, C. J., and Moore, B. 1991. Modelling basin scale hydrology in support of physical climate and global biochemical studies: An example using the Zambezi River, Surv. Geophys. 12, 271-311.
14. Vörösmarty, C. J., Douglas, E., Green, P. and Revenga, C. 2003. Geospatial indicators of emerging water stress: An application to Africa, Ambio.

Ecosystems

1. Centre for Development Corporation Services, Free University, Amsterdam. 1992. Soil and water conservation in sub-Saharan Africa. International Fund for Agricultural Development (IFAD).
2. Chakela, Q.K (ed) 1990. State of the environment in Lesotho 1997. NES: Maseru
3. Chenje, M. and Johnson, P. (eds.) 1994. State of the environment in southern Africa. Southern African Research and Documentation Centre, IUCN & SADC.
4. Cowan, G.I. (ed.) 1995. Wetlands of South Africa. Department of Environmental Affairs and Tourism, Pretoria.
5. Davies, B.R. 1986. The Zambesi River system. In: Davies, B.R. and Walker, K.F. (eds.) 1986. The ecology of river systems. Dr. W. Junk Publishers, Dordrecht, The Netherlands.
6. Davies, B.R. and Day, J.A. 1986. The biology and conservation of South Africa's vanishing waters. The Centre for Extra-Mural Studies, University of Cape Town, South Africa.
7. Department of Natural Resources, Zambia. 1990. The state of the environment report of Zambia.
8. Government of Malawi 1998. State of the environment report for Malawi 1998. Environmental Affairs Department: Lilongwe
9. Henderson, L. 1999. The southern African plant invaders atlas (SAPIA) and its contribution to biological weed control, In: T. Olckers and M. P. Hill (eds.), Biological control of weeds in South Africa (1990 – 1998), African Entomology Memoir No.1 pp 103-112.
10. IUCN. 1998. The nature of Zimbabwe. IUCN, Gland, Switzerland.
11. Moyo, S., O'Keeffe, P. & Sill, M. 1993. The southern African environment. Profiles of the SADC Countries. Earthscan Publications, London.
12. O'Keeffe, J.H.O. (ed.) 1986. The conservation of South African rivers. South African National Scientific Programmes Report No. 131, CSIR.
13. Rudengre, J., Bullock, A., Schmidt, M. and Williams, H. 1997. Environmental security and water management in southern Africa.
14. SADC ELMS 1996. SADC policy and strategy for environment and sustainable development. – Toward equity-led growth and sustainable development in southern Africa. SADC ELMS: Maseru
15. Skelton, P. 1993. A complete guide to freshwater fishes of Southern Africa. Southern Book Publishers: Johannesburg
16. Southern African Sub-Regional Environmental Group. 1985. State of the environment report, Swaziland.
17. Tiffen, M. & Mulele, M.R. 1994. The environmental impact of the 1991-92 drought on Zambia. IUCN, Gland, Switzerland and Lusaka, Zambia.
18. Turpie, J., Smith, B., Emerton, L. and Barnes, J. 1998. Economic value of the Zambezi Basin wetlands. Phase I Report, unpublished. ZBWCRUP and NETCAB programmes, IUCN: Harare.
19. Whitlow, R. J. 1988. Land degradation in Zimbabwe: A geographical study, Natural Resources Board, Harare.

20. World Bank. 1989. National environmental action plan. Kingdom of Lesotho.

Hydrology

1. Chenje, M. and Johnson, P. (eds.). 1996. Water in Southern Africa, SADC/IUCN/SARDC, Maseru/Harare, pp. 238.
2. Conley, A. and Van Niekerk, P. (1998) Sustainable Managment of International Waters: The Orange River case, in H. Savenije and P. van der Zaag, The Management of Shared River Basins: Experiences from SADC and EU. Delft, The Netherlands: Ministry of Foreign Affairs.
3. David, L.J. 1988. Environmentally sound management of the Zambezi River basin. Water resources development 4(2): 80-112
4. Department of Water Affairs, South Africa. 1986. Water transfer schemes in RSA.
5. DNA (National Directorate of Water). 1999. Water Resources of Mozambique: Synopsis 1999, Ministry of Public Works and Housing, Republic of Mozambique, Maputo.
6. Gash, J.H.C., Odada, E.O., Oyebande, L. and Schulze, R.E. (eds.) 1999. Freshwater Resources in Africa. Proc. of a workshop, Nairobi, Kenya, October, 1999.
7. Government of Zambia. 1997. Zambia country situation report on water. Paper prepared for the SADC roundtable conference, Lusaka.
8. Matiza, T. and Dale, P. (eds.) 1993. Zambesi Basin water projects. Proceedings of a workshop held at Kasane, Botswana: 28 April – 2 May 1993. IUCN Regional Office for Southern Africa, Harare, Zimbabwe and SADC ELMS, Maseru, Lesotho.
9. Mavimbela, S.S.K. 1992. Diminishing freshwater resources in the Kingdom of Swaziland. Dresden University of Technology.
10. Midgley, D.C., Pitman, W.V. and Middleton, B.J. 1994. Surface water resources of South Africa 1990, User's Manual, Volumes II and III: Drainage regions C, D, F – Appendices and books of maps; WRC 298/1;2.1; 2.2/94.
11. Nilsson, A and Hammar, A. 1995. Study of water resources in Zimbabwe. Geoscope AB. Stockholm.
12. Ohlsson, L. 1995. Water and security in southern Africa. A desktop study for SIDA. Padrigu.
13. Olivier, H. Great Dams in Southern Africa. Purnell, Cape Town.
14. Schulze, R.E. 1997. South African Atlas of agrohydrology and climatology. Water Research Commission, Pretoria, Report TT82/96.
15. South African National Committee on Large Dams. 1994. Large dams and water systems in South Africa. J.P. van der Walt and Son, Pretoria.
16. UN FAO 1995. Water resources of the African countries: A review. FAO: Rome.
17. Wallis, S. 1992. Lesotho Highlands Water Project. Trans-Caledon Tunnel Authority, Pretoria, South Africa.
18. Water Research Commission. 1994. Orange River Losses, Phase 1 summary report. Department of Water Affairs and Forestry, South Africa.

Hydrogeology

1. Beekman, H.E., Gieske, A.M.S. and Selaolo, E.T. 1996. GRES: Groundwater recharge studies in Botswana 1987-1996. Botswana J. of Earth Sci., Vol. III, 1-17.
2. Beekman, H.E., Selaolo, E.T. and de Vries, J.J. 1999. Groundwater recharge and resources assessment in the Botswana Kalahari – Executive summary GRES-II, GCA Amsterdam, ISBN 90-9012825-5, pp. 48.
3. Botha, J. F., Verwey, J. P., van der Voort, I., Vivier, J. J. P., Buys, J., Colliston, W. P., and Loock, J. C. 1998. Karoo Aquifers: Their Geology, Geometry and Physical

Properties, WRC Report No. 487/1/98, Water Research Commission, Pretoria, South Africa.

4. Bredenkamp, D.B., Botha, L.J., Van Tonder, G.J. and Van Rensburg, H.J. 1995. Manual on quantitative estimation of groundwater recharge and aquifer storativity. Water Research Commission Report TT 73/95, ISBN 1-86845-176-3, pp. 363.
5. Chilton, J. and Foster, S. 1995. Hydrogeological characterisation and water-supply potential of basement aquifers in tropical Africa. Hydrogeology Journal, V. 3, No. 1, pp 36 – 49.
6. Chilton, J. 2000. Groundwater Research Priorities for the SADC Region: Report on a workshop at the IAH 30th Congress, Cape Town, November 2000. British Geological Survey, Technical Report IR/01/27.
7. Department of Water Affairs, Botswana. 1992. Botswana National Water Master Plan, Vol. 5, Hydrogeology.
8. Department of Water Affairs, Namibia. Annual Reports (01/04/1990 to 31/03/1991 and for 91/92, 92/93/ 93/94).
9. Department of Water Affairs, Namibia. 1995. Rural water supply in Namibia.
10. Department of Water Development, Zimbabwe. 1985. National Master Plan for rural water supply and sanitation, Vol. 2, Hydrogeology; Regional hydrogeological maps (4) of Zimbabwe, scale: 1:500 000.
11. Gabaake, G. G. 1997. GRES with respect to general water resources needs in Botswana, Ministry of Minerals, Energy and Water Affairs, Gaborone, Botswana; paper presented at the Groundwater Recharge Evaluation Studies (GRES) Symposium, 3 Nov. 1997.
12. Gieske, A.M.S. 1992. Dynamics of groundwater recharge – A case study in semi-arid eastern Botswana, Ph.D. thesis Vrije Univ. Amsterdam, pp. 289.
13. MacDonald, A. and Davies, J. 2000. A brief review of groundwater for rural water supply in sub-Saharan Africa, BGS Technical Report WC/00/33.
14. SADC Groundwater management programme. Compilation of a regional hydrogeological map and atlas for the SADC region.
15. United Nations 1988. Ground Water in eastern, central and southern Africa. Natural Resources/Water Series No. 19.
16. Vegter, J. R. 1995. Groundwater Resources of South Africa: An explanation of a set of national groundwater maps, Report No. TT74/95, Water Research Commission, Pretoria.
17. Vegter, J. R., Seymour, A. J. and Simonic, M. 1995. Groundwater resources of the Republic of South Africa. A set of 7 maps, Water Research Commission and the Department of Water Affairs and Forestry.
18. Vegter, J. R. 2001. Groundwater Development in South Africa and an introduction of the hydrogeology of groundwater regions, Report No. TT134/00, Water Research Commission, Pretoria.
19. Visser, D. J. L. 1989. The geology of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland, Explain. Geol. Map (1:1 million), Geol. Surv. S. Afr.
20. Ward, V. 1992. Water in Namibia. Desert Research Foundation of Namibia, Windhoek.
21. Wright, E. P. (ed.). 1992. The hydrogeology of crystalline basement aquifers in Africa, Spec. Publ. No. 66, Geol. Soc. London.
22. Xu, Y. and Beekman, H.E. (eds.). 2003. Groundwater recharge estimation in Southern Africa. UNESCO IHP Series No. 64, UNESCO Paris, ISBN 92-9220-000-3, pp. 207.

Socio-Economy

1. Allan, J.A. 1996. The political economy of water: reasons for optimism but long-term caution, in Water, Peace and the Middle East Negotiating Resources in the Jordan Basin. London: Taurus academic studies.
2. Allan, J.A. 2002. Water resources in semi-arid regions: Real deficits and economically invisible and politically silent solutions, In: Turton, A., and Henwood, R., (eds.), Hydropolitics in the developing world – A southern African perspective, African Water Issues Research Unit, Pretoria, 23-36.
3. Arntzen, J. 2001. Sustainable water management in Southern Africa: An integrated perspective, In: Gash, J. H. C., Odada, E. O., Oyebande, L., and Schulze, R. E. (Eds.): Freshwatrer Resources in Africa, Proceedings of a workshop, Nairobi, Kenya, October 2999, Biospheric Aspects of the Hydrological Cycle, pp 81 – 87.
4. Ashton, P.J. 2000. Are southern African water conflicts inevitable or preventable? In: (Solomon, H. & Turton, A.R. Eds), Water Wars: An Enduring Myth or an Impending Reality? ACCORD Publishers, Durban, 65-102.
5. Ashton, P.J. 2002. Avoiding Conflicts over Africa's Water Resources, Ambio, Vol. 31, No. 3, 236–242.
6. Ashton, P.J. and Ramasar, V. 2002. Water and HIV/AIDS: Some strategic considerations in Southern Africa. In: (A.R. Turton & R. Henwood, Eds) Hydropolitics in the Developing World: A Southern African Perspective. Pretoria: African Water Issues Research Unit (AWIRU), 217-235.
7. Basson, M.S. 1997. Overview of water resources availability and utilization in South Africa.
8. Beson, C. and Clay, E. 1994. The impact of drought on Sub-Saharan African economies: A preliminary examination. Working paper 77. Overseas Development Institute: London.
9. Brookings Institution. 2001. The economic impact of HIV/AIDS in southern Africa, Conference Report, No. 9.
10. Christian Aid 2002. Will Southern African Countries reach the Millennium Development Goals? Briefing by the Southern Africa Regional Team April 2003.
11. Deichmann, U. 1994. A medium Resolution Population Database for Africa. NCGIA, University of California, Santa Barbara.
12. Earle, A. and Turton, A. 2003. The virtual water trade amongst countries of the SADC. Proc. of the International Expert Meeting on Virtual Water Trade (Ed. A.Y. Hoekstra), Delft – The Netherlands, 12-13 Dec. 2002, Value of Water Research Report Series no. 12, 183-200.
13. Grey, D and Sadoff, C. 2002. African water resources and poverty in Africa: Essential economic and political responses. Discussion paper presented to the African Regional Ministerial Conference on Water in Abuja, Nigeria in April 2002.
14. Heyns, P. 2002. The interbasin transfer of water between SADC countries: A developmental challenge for the future, In: Turton, A., and Henwood, R., (eds.), Hydropolitics in the developing world – A southern African perspective, African Water Issues Research Unit, Pretoria ,157-176.
15. Hoekstra, A.Y. 2003. Virtual water: An introduction. Proc. of the International Expert Meeting on Virtual Water Trade (Ed. A.Y. Hoekstra), Delft – The Netherlands, 12-13 Dec. 2002, Value of Water Research Report Series no. 12, 13-23.
16. HSRC, The Role of the State in Economic Development in Southern Africa: http://www.sarpn.org.za/
17. Jubilee 2000 webpage - http://www.jubilee2000uk.org

18. Meissner, R. 2003. Regional food security and virtual water: Some natural, political and economic implications. Proc. of the International Expert Meeting on Virtual Water Trade (Ed. A.Y. Hoekstra), Delft – The Netherlands, 12-13 Dec. 2002, Value of Water Research Report Series no. 12, 201-219.
19. Nepad website - www.nepad.org
20. SADC (2000). SADC review and country profiles, Gaborone, Botswana.
21. SADC 2000. SADC statistics: facts and Figures 2000. SADC secretariat: Gaborone.
22. Sadoff, L., Whittington, D. and Grey, D. 2003. Africa's International Rivers: An Economic perspective, The World Bank, Washington, D.C.
23. Sharma, N. P., et al. 1996. African Water Resources: Challenges and opportunities for sustainable development, World Bank, Washington D.C., WB T.P. No. 331.
24. Turton, A. and Ohlsson, L. (eds.) 2000. Water scarcity and social stability: Towards a deeper understanding of the key concepts needed to manage water scarcity in developing countries. SOAS Water Isues Study Group Occasion Paper 17. University of London, London.
25. Turton, A. and Henwood, R. (eds.) 2002. Hydropolitics in the developing world: A Southern African perspective, African Water Issues Research Unit, Pretoria.
26. UNECA (United Nations Economic Commission for Africa) 2002. Report on the Economic and Social Conditions in Southern Africa: 2000 (Draft), Subregional Development Centre For Southern Africa (ECA/SRDC-SA).
27. Whiteside A. W. and Sunter C. 2000. AIDS: The challenge for South Africa, Human and Rosseau/Tafelberg, Cape Town.

Management

Legislation, regulations and guidelines

Lesotho

1. Government of Lesotho. 1998. National environment policy for Lesotho (revised). Lesotho National Environment Secretariat: Maseru

Malawi

2. Government of Malawi (GOM) Ministry of Water Development 1999: Water Resources Management Policy and Strategies (WRMPS), Lilongwe.
3. Government of Malawi (GOM) Ministry of Water Development 1999: Draft Water Act. Water Resources Development Policy and Strategies. Lilongwe. Annex B.
4. Government of Malawi (GOM) Ministry of Local Government: National Decentralization Policy, Lilongwe, Malawi.

Mozambique

5. Governo de Mozambique 1991. Lei de Aguas (Lei no 16/91).

Namibia

6. Government of the Republic of Namibia, Ministry of Agriculture, Water and Rural Development 2000. National Water Policy White Paper, August 2000, pp. 45.
7. Government of the Republic of Namibia 2001. Water Resources Management Bill (Final Draft).
8. Namibian Water Resources Management Review 2003. Technical team – Progress of the project presented at the GTZ Water Sector Network Meeting, March 25-27, 2003, Windhoek, Namibia.

South Africa http://www.dwaf.gov.za/Documents/

9. Department of Water Affairs and Forestry 1996. SA Water Quality Guidelines, Vols 1-7, DWAF, Pretoria.

10. Department of Water Affairs and Forestry, Department of Health, Water Research Commission 1998. Quality of Domestic Water Supplies, Vols 1 – 5, Water Research Commission, Pretoria.
11. Department of Water Affairs 1998. Minimum Requirements for water monitoring at waste management facilities, Second Edition, DWAF, Pretoria.
12. Department of Water Affairs & Forestry 1999a. Resource directed measures for protection of water resources, Vol. 6: Groundwater Component Version 1.0, Pretoria.
13. Department of Water Affairs and Forestry 1999b. Water Resources Protection Policy Implementation, Resource Directed Measures for protection of water resources, Integrated Manual, Report no N/28/99, DWAF, Pretoria.
14. Department of Water Affairs and Forestry 1999c. General Authorisations in terms of section 39 of the National Water Act, Government Gazette No. 20526, Pretoria.
15. Department of Water Affairs and Forestry 2000. Policy and Strategy for groundwater quality management in South Africa, W1.0 1st Ed. 2000. Formeset Pr. Cape, Pretoria.
16. Department of Water Affairs and Forestry. 2001. A Guide to Strategic Environmental Assessment for Water Use in Catchments, Draft Document, September 2001, DWAF, Pretoria.
17. Department of Water Affairs and Forestry 2002. Integrated Water Resource Management: Guidelines for Groundwater Management in Water Management Areas, South Africa – Working Draft, DWAF, Pretoria.
18. Government of the Republic of South Africa 1997. Water Services Act. Act no. 108 of 1997. Government Gazette Vol. 390, Cape Town, Republic of South Africa.
19. Government of the Republic of South Africa 1998. National Water Act (1998). Act no. 36 of 1998. Government Gazette Vol. 398, Cape Town, Republic of South Africa.

Swaziland

20. Government of Swaziland 1998, Proposed Water Act.

Zambia

21. Government of the Republic of Zambia. 1949. The Water Act, Chapter 198 of the Laws of Zambia.
22. Government of the Republic of Zambia. 1987. The Zambezi River Authority Act, Chapter 467 of the Laws of Zambia.
23. Government of the Republic of Zambia, Ministry of Energy and Water Development. 1994. National Water Policy, Government Printer, Lusaka.
24. Government of the Republic of Zambia. 1997. The Water Supply and Sanitation Act No 28 of 1997, 239-266.
25. Phiri, Z. 2000. Water Law, Water Rights and Water Supply in Zambia – Issues and Perspectives, Proc. 1st WARFSA/WaterNet Symposium: Sustainable Use of Water Resources, Maputo, 1-2 Nov. 2000, pp. 9.

Zimbabwe

26. Government of the Republic of Zimbabwe. 1998. Water Act [Chapter 20: 24] No. 31/98, Government Printer, Harare, 459-531.
27. Government of the Republic of Zimbabwe. 1998. Zimbabwe National Water Authority Act [Chapter 20: 25] No. 11/98, Government Printer, Harare, 215-240.
28. Government of the Republic of Zimbabwe – Ministry of Rural Resources and Water Development – Department of Water Development. 1999. Guidelines for Boreholes, Groundwater Monitoring and Groundwater Use, Final Draft, September 1999.
29. Government of the Republic of Zimbabwe. 2000. Water (Catchment Councils) Regulations [Chapter 20: 24] Government Printer, Harare, Statutory Instrument 33 of 2000, 257-270.

30. Government of the Republic of Zimbabwe. 2000. Water (Sub-Catchment Councils) Regulations [Chapter 20: 24] Government Printer, Harare, Statutory Instrument 47 of 2000, 359-376.
31. Government of the Republic of Zimbabwe. 2000. Water (Waste and Effluent Disposal) Regulations [Chapter 20: 24] Government Printer, Harare, Statutory Instrument 274 of 2000, 1575-1606.
32. Government of the Republic of Zimbabwe. 2001. Water (Permits) Regulations [Chapter 20: 24] Government Printers, Harare, Statutory Instrument 206 of 2001, 1345-1442.
33. Sunguro, S., Beekman, H.E. and Erbel, K. 2000. Groundwater regulations and guidelines: crucial components of integrated catchment management in Zimbabwe, Proc. 1st WaterNet/Warfsa Symp. 'Sustainable Use of Water Resources', Maputo, 1-2 Nov. 2000, pp. 7.

SADC (sadcrsap@botsnet.bw)

34. SADC 1995. Protocol on Shared Watercourse systems in the Southern African Development Community Region http://www.thewaterpage.com/sadcWSCU.htm
35. SADC 1999. Consolidated Version of the SADC Protocol, containing Original Provisions and Proposed Amendments.

Water Sector Reform - IWRM

1. Alemu, S., Granit, j., Grey, D. and Sadoff, C. 2001. The importance of integrated water resources management for the economies of the countries in southern Africa. In-house draft/work-in-progress. Africa region, World Bank: Washington DC.
2. Ashton, P. 2000. Integrated Catchment Management: Balancing Resource Utilization and Conservation, Course Notes: Aquatic Biomonitoring Course, Grahamstown, 21-23 February 2000.
3. Chikozho, C. 2002. Institutional Development under Water Sector Reforms: lessons from the Mazowe Catchment in Zimbabwe, Proc. 3rd WaterNet/Warfsa Symp. 'Water Demand Management for Sustainable Development', Dar es Salaam, 30-31 Oct. 2002, pp. 11.
4. Goldblatt, M., Ndama, J., van der Merwe, B., Gomes, F., Haasbroek, B. and Arntzen, J. 2000. Water demand management: Towards developing effective strategies for southern Africa. IUCN ROSA: Harare
5. Gonese, F.T. 2002. Broadening Access and Integrating Water Management Institutions: Water Sector Reforms in Zimbabwe and Malawi; Preliminary Observations, Proc. 3rd WaterNet/Warfsa Symp. 'Water Demand Management for Sustainable Development', Dar es Salaam, 30-31 Oct. 2002, pp. 11.
6. Grey, D. 1996. A water resource management assistance strategy for SADC Member States. World Bank internal discussion draft. World Bank: Washington DC.
7. GWP-SA: Global Water Partnership Southern Africa – http://www.gwpforum.org/servlet/PSP?iNodeID=133
8. Hirji, R., Johnson, P., Maro, P. and Matiza Chiuta, T. (eds.). 2002. Defining and Mainstreaming Environmental Sustainability in Water Resources Management in Southern Africa. SADC/IUCN/SARDC/World Bank: Maseru/Harare/Washington DC, pp. 318.
9. Macy, P. 1999. Urban water demand management in southern Africa: The conservation potential. Sida publications on water resources (13).
10. Pallett, J. (ed.). 1997. Sharing water in southern Africa. Desert Research Foundation of Namibia, Windhoek, pp. 121.

11. Reed, D., de Wit, M., Basson, J., Mackay, H. and Lahiff, E. 2003. Conclusions and recommendations. In "Towards a just South Africa – The economy of natural resource wealth" (eds. Reed, D. and de Wit, M.), 99-114.
12. Richards, A. 2002. Coping with Water Scarcity: The Governance Challenge. Institute on Global Conflict and Cooperation. Policy Paper no. 54. ISSN: 1088-2081.
13. SADC Water Sector 1998. Regional strategic action plan for integrated water resources development and management in the SADC countries (1999 – 2004): Summary report. SADC WSCU: Maseru.
14. Savenije, H. and van der Zaag, P. 1998. The Management of Shared River Basins: Experiences from SADC and EU. Ministry of Foreign Affairs, The Netherlands.
15. Seyam, I. 1999. Algorithms for sharing Zambezi water resources, SSRZ Seminar II, OTD St. Lucia Park, Harare, November 4 to 6, 1999.
16. Shela, O.N. 1998. Management of shared river basins – Zambezi River Case Study. In H. Savenije and P. van der Zaag, The Management of Shared River Basins: Experiences from SADC and EU. Delft, The Netherlands: Ministry of Foreign Affairs.
17. Stein, R. 2002. Water sector reforms in southern Africa: some case studies. In Hydropolitics in the developing world – A southern African perspective, A. Turton and R. Henwood (eds.), AWIRU, 113-123.
18. UNECA (United Nations Economic Commission for Africa) 1999. Report of the meeting of Chief Executives of Transboundary River/Lake Basin Organizations in Africa, Addis Ababa, Ethiopia
19. UNECA (United Nations Economic Commission for Africa) 2000. Transboundary River/Lake Basin water development in Africa: Prospects, Problems, and Achievements, ECA/RCID/052/00, Addis Ababa, Ethiopia.
20. Water Tech. 1999. Integrated catchment management strategy in Zimbabwe, Report to the Water Resources Management Strategy Technical Secretariat, Department of Water Development, Harare.

Water Master Plan

Angola

1. Quintino, M. 1994. Country report on Zambesi River Basin (Angola). SADC- ELMS, Maseru.

Botswana

2. Government of Botswana 1992. Botswana National Water Master Plan Study, Ministry of Minerals, Energy and Water Affairs, Department of Water Affairs.

Malawi

3. Government of Malawi 1997. The country situation report on water resources in Malawi. Lilongwe

Mozambique

4. Government of Mozambique 1998. Country situation report – water resources. Maputo

Namibia

5. Government of Namibia 1998. Country situation report. Windhoek

South Africa

6. Government of South Africa 2002. Proposed First Edition National Water Resources Strategy – August 2002, Department of Water Affairs and Forestry, Pretoria.

Zambia

7. Government of the Republic of Zambia, Ministry of Energy and Water Development and Japan International Cooperation Agency 1995. Study on the National Water Resources Master Plan in the Republic of Zambia.

8. Government of the Republic of Zambia, Ministry of Energy and Water Development, Water Resources Action Program (WRAP) 2003. Draft concept and component papers on (1) Institutional and legal framework; (2) Water resources information; (5) Economics and financing and (6) Water and the environment, Lusaka, Zambia, January 2003.
9. Government of Zambia 1997. Country situation report on water. Lusaka.

Zimbabwe

10. Government of Zimbabwe - Ministry of Rural Resources and Water Development 2001. Towards Integrated Water Resources Management: Water Resources Management Strategy for Zimbabwe, Harare, Zimbabwe, WRMS Secretariat, pp. 132.
11. Government of Zimbabwe 1997. Zimbabwe country situation report on water sector. Harare.

Data-bases and maps

1. Each SADC country has its own GIS coverages/maps and specific data-bases on physiographic, socio-economic and management information, however, at different (temporal and spatial) scales and with different reliability.

Digital Coverage

1. Deichman, U. 1994. A medium resolution population database for Africa, National centre for Geographic Information and Analysis, University of California, Santa Barbara, USA.
2. FAO-Aquastat:(Rivers,Dams,Hydrogeology) http://www.fao.org/waicent/faoinfo/agricult/agl/aglw/aquastat/main/index.stm
3. GRID Center GRID-Geneva: Atmosphere, Biodiversity, Boundaries, Climate, Ecological/life zones, Human related Hydrology, Land Cover, Oceans & Seas, Physical Geography, Soils, Vegetation index
4. NOAA Coastline, http://rimmer.ngdc.noaa.gov/coast/, Coastline of Africa.
5. Ramsar sites, From Ramsar sitelist file “List of Wetlands of International Importance” downloaded from Ramsar website http://www.ramsar.org/
6. UNEP 2002. GEO-3: Past, present and future perspectives, United Nations Environment Programme.
7. UNEP Spatial Characterisation Tool, Corbett, J.D. & O’Brien, R.F., The Spatial Characterisation Tool – Africa V.1.0, Texas Agricultural Experiment Station, Texas A and M University, Blackland Research Centre Report No. 97-03. (demographics, ppt/pet ratio, basin cover)
8. UNEP, Vulnerability of Water Resources to Environmental Change in Africa: http://www.unep.org/dewa/water/Vulnerability/Africa_Hme.html
9. USGS MODIS cover of Africa, Africa Mosaic from MOD09A1, MODIS Rapid Response Web Fire Maps Land Use Change Initiative, Samuel Alleaume, Department of Geography, University of Maryland, Feb 2002: http://rapidfire.sci.gsfc.nasa.gov/, - Data captured 20011016, MODIS Image Mosaic of Africa.
10. USGS World Energy Resources page: http://energy.cr.usgs.gov/oilgas/wep/products/geology/africa.htm, OFR 97-470A, reclassified, after Blackburn et al (see BGS report) (Hydrogeological Domains)
11. World Resources Institute 1998. Watersheds of the World CD, IUCN website: http://www.iucn.org/themes/wani/eatlas.

5.2 Global

Only few references to literature relating to the vulnerability assessment of water resources to environmental change in Africa are listed below.

Physiography

Climate Change and Impacts

1. Alcamo J., Henrichs T., Rösch T. 2000. World Water in 2025 – Global modeling and scenario analysis for the World Commisssion on Water for the 21st Century, Report A0002, Center for Environmental Systems Research, University of Kassel, Germany.
2. Alcamo, J. and Henrichs, T. 2002. Critical regions: A model based estimation of world water resources sensitive to global changes. Aquatic Sciences, 64, 1-11.
3. Alcamo, J., Marker, M., Florke, M. and Vassolo, S. 2002. Preliminary findings from assessing global climate impacts on water resources and hot spot regions, CESR, Univ. Kassel. Interim report of the project Global Analysis and Global Information for the Dialogue on Water and Climate (WAT-CLIM), Kassel, Germany.
4. Appleton, B. (ed.) 2003. Climate changes the water rules: How water managers can cope with today's climate variability and tommorow's climate change. Dialogue on Water and Climate. Printfine Ltd, Liverpool, UK, ISBN: 90-327-0321-8.
5. Arnell, N. W. 1999. Climate change and global water resources, Global Environmental Change, 9, S31 – S49.
6. Gleik, P.H. 2000. Water: Potential consequences of climate variability and change for water resources of the United States. Report of the Water Sector Assessment Team for the U.S. Global Change Research Program. GRID-Arendel, 1990/1999/2002
7. IPCC (Intergovernmental Panel on Climate Change) 1996. Climate Change 1995 – The science of climate change, Contribution of Working Group I to the 2nd Assessment Report of the IPCC, Cambridge University Press.
8. IPCC. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability, Intergovernmental Panel on Climate Change, Cambridge University Press.
9. IPCC. 2002. Climate Change and Biodiversity, Intergovernmental Panel on Climate Change, Cambridge University Press.
10. Parry, M. Rosenzweig, C., Iglesias, A., Fischer, G. and Livermore, M. 1999. Climate change and world food security: a new assessment, Global Environmental Change 9, S51 - S67.
11. Ragab, R.; Prudhomme, C. 2001. Climate Change and Water Resources Management in Arid and Semi-arid Regions: Prospective and Challenges for the 21st Century, Biosystems Engineering (2002) 81 (1), pp 3 – 34.
12. Rosegrant, M., Cai, X. and Cline S. 2002. World Water and Food to 2025: Dealing with Scarcity, International Food Policy Research Institute, Washington, D.C. ISBN 0-89629-646-6.
13. Vörösmarty, C. J., Green, P., Salisbury, J. and Lammers, R. 2000. Global water resources: Vulnerability from climate change and population growth, Science 289, pp 284 – 288.

Climate Change Research Programmes

1. DEKLIM: German Climate Research Programme, http://www.deklim.de
2. DWC: Dialogue on Water and Climate, http://www.waterandclimate.org
3. FRIEND: Flow Regimes from International Experimental and Network Data - http://www.nwl.ac.uk/ih/www/research/bfsafrican.html
4. GEO3: Global Environment Outlook, http://www.unep.org/GEO/geo3/

5. GLOWA: Global Change in the Hydrological Cycle - http://www.glowa.org
6. GWSP: Global Water System Project – http://www.gwsp.org

Ecosystems

1. Revenga, C. Brunner, J. Henninger, N. Kassem, K. and Payne, R. 2000. Pilot analysis of global ecosystems: Freshwater Systems, World Resources Institute, ISBN: 1-56973-460-7.

Socio-Economy

1. Dinar, A. Balakrishnan, T.Wambia,. J. 1998. Political economy and political risk of institutional reform in the water sector. World Bank, Policy Research Working Paper 1987.
2. CIA (2000) The world factbook: Country listing, Central Intelligence Agency (USA), Washington DC. www.cia.gov/cia/publications/factbook/geos/.
3. PAI 2000. People in the balance: Population and natural resources at the turn of the millennium. Population Action International: Washington DC.
4. UNAIDS (2000) Epidemiological fact sheets on HIV/AIDS and country profiles, UNAIDS/WHO, Geneva. www.unaids.org/countryprofiles
5. United Nations Population Fund. 1994. World population prospects: the 1994 revision.
6. United Nations - World Water Development Report 2003. Water for People Water for Life (World Water Assessment Programme), Executive Summary: http://www.unesco.org/water/wwap/wwdr
7. World Bank (1998), World development indicators 1998, World Bank, Washington DC.

Management

Legislation, regulations and guidelines

1. United Nations 1992. Rio Declaration on Environment and Development, United Nations Conference on Environment and Development, Rio de Janeiro, Brazil.
2. United Nations 2000. United Nations Millennium Declaration, Resolution adopted by the General Assembly of the United Nations, A/55/L.2.
3. United Nations 2002. Johannesburg Declaration on Sustainable Development, World Summit on Sustainable Development, Johannesburg, South Africa.