

Water systems occur at many scales from local to global and ultimately are all interlinked. While it is important to understand these linkages at all scales it is often most useful to view surface water at the level of the basin. Hydrological basins are an important unit of management for most of the ecosystem services upon which humans and natural systems depend. Surface water flows across basins and sub-basins unite areas by providing common water sources, aquatic habitats, transportation networks, quality water, hydropower potential and other shared goods and services. This is borne out by the formation of numerous multi-national basin management organizations worldwide, with several notable examples in Africa. The continent also has many transboundary aquifer systems, about which much less is known. While their connections are less obvious than are those of river and lake basins, their management is also well served by basin-scale management, and like surface water basins, the emerging formation of multi-national groundwater basin management organizations is testimony to this reality.

Most people in Africa live in rural areas and are still heavily dependent on agriculture for their livelihoods. This makes water an especially vital economic and social commodity. Along with a growing population, the extreme variability of rainfall on Africa's landscapes—from arid northern and southern regions to the continent's belt of tropical forests—poses many challenges to providing safe drinking water and sanitation for millions of people. Consequently, transboundary water resource management requires an enabling environment that encourages cooperation on numerous fronts.

An important part of this enabling environment is the availability of adequate information about surface and groundwater upon which policy makers can make informed management decisions. Data for Africa's water resources remain incomplete and inconsistent, particularly for groundwater resources. Building on a foundation of detailed, consistent, accurate and available data is one of the central challenges for Africa's water future. The emergence of transboundary basin organizations for many of Africa's large basins may provide a powerful opportunity to build part of this foundation.

# *Transboundary Surface Water Basins*

Worldwide, there are 263 transboundary river basins, which can be defined as basins shared by two or more riparian states. Approximately 60 per cent of the world's population depends on these international water systems (UNU 2006). Transboundary river basins are also important because of the complex natural ecosystems they support. The potential increase in conflicts over shared water resources as well as the effects of climate change represent

significant social, economic and environmental threats. In addition, there is a growing danger to human health from inadequate or unsafe water supplies (UNEP 2006a).

Africa's 63 international transboundary river basins cover about 64 per cent of the continent's land area and contain 93 per cent of its total surface water resources (Figure 2.1). They are also home to some 77



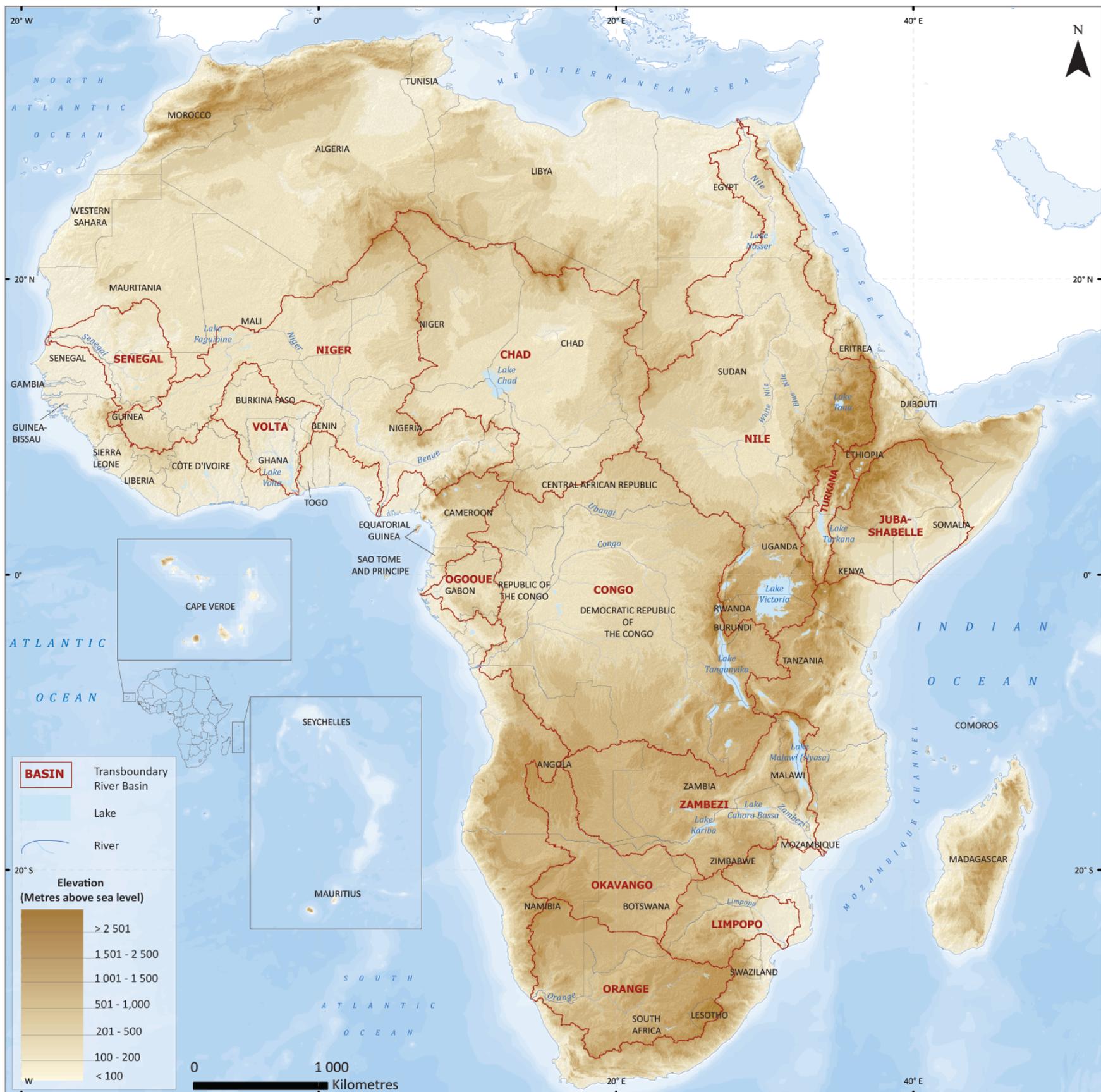


Figure 2.1: Africa's major transboundary river basins

per cent of Africa's population. The Nile River Basin is the most highly populated in all of Africa with over 220 million people—nearly a quarter of Africa's total population (SEDAC 2010). Fifteen principal lakes and 24 main watersheds also cross the political boundaries of two or more countries in Africa (UNEP 2006b). The catchment areas of the 17 largest river and lake basins on the continent exceed 100 000 km<sup>2</sup> in size and are therefore classified as large basins (UNU 2006).

The complexity of the physical, political and human interactions within transboundary river basins can make equitable management of their risks, costs and benefits especially challenging. Quite often the resources are not evenly distributed by area or population. This often puts upstream areas or nations in a position of advantage over their downstream neighbours. Examples of this can be seen in the

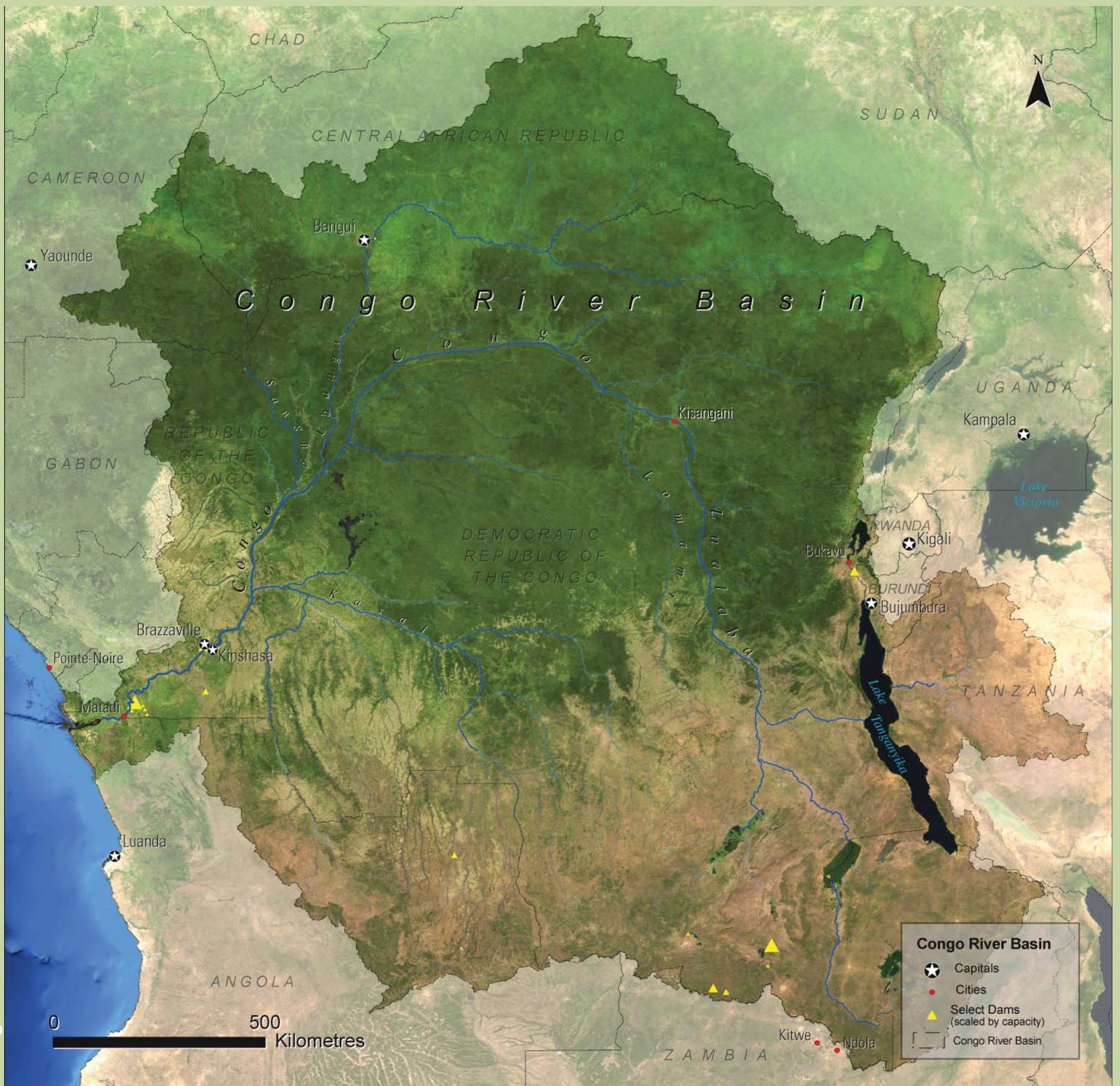
Niger Basin, Juba-Shabelle Basin, Okavango Basin and others. The degree and type of dependence on the common resources might also vary greatly within a basin. For example, on the Nile, Uganda is highly dependant upon the river for hydropower and manages it accordingly, however downstream it is water for agriculture that Egypt counts on most from the Nile.

The major transboundary basins of Africa present a variety of challenges and opportunities to the people and countries who share them. Each basin differs in many ways from the others but all share common attributes as well. The basin-scale profiles that follow present some of that diversity and commonality through common measures such as population and precipitation, and bring to life some of the management challenges and opportunities with specific cases within the basins.

# Congo River Basin



The Congo Basin is a vast 3 700 000 km<sup>2</sup> depression extending nearly 2 000 km across both its north-south and east-west dimensions. It straddles the equator, gathering heavy precipitation that falls on the tropical rainforests covering much of its extent.



The Congo River runs 4 670 km in a counter-clockwise arc around eastern and northern Democratic Republic of Congo, finally turning west toward the Atlantic Ocean where it discharges 40 000 m<sup>3</sup> of water every second (Laraque and others 2001). Its volume is equal to 32 per cent of Africa's total renewable water resources. It is believed to be the deepest river in the world, with recent measurements showing a point over 200 m deep (USGS 2009). The river and its tributaries are a dominating feature in the basin's natural systems and in the livelihoods of the basin's population.

The Congo Basin river systems are an enormous resource for transportation and power generation. They have productive fisheries and potential for irrigation as well, but are widely seen as under-developed and under-managed. Sustainable development of the basin's vast potential will require effective transboundary cooperation among the countries that overlap the Congo River Basin—eleven in all. Four of the countries (Central African Republic, Cameroon, Democratic Republic of the Congo and Republic of the Congo) are already cooperating through the Commission Internationale du Bassin Congo-Oubangui-Sangha (CICOS) to further the development of the basin's potential. One of the keys to its goal of successful sustainable utilization will be improving data collection, processing, and management to provide the scientific basis for decision making.

### Population

Approximately one hundred million people live in the Congo Basin with three-quarters of them living in the Democratic Republic of the Congo (DRC) (SEDAC 2010) (Figure 2.2.1). The most dense populations in the basin are along the DRC's border with Burundi and Rwanda on the basin's eastern edge and in the area between Kinshasa and Mbuji-Mayi. Rwanda's population density within the basin is around 400 persons per km<sup>2</sup> and Burundi's is just over 300 persons per km<sup>2</sup>. Roughly seven million Tanzanians live within the basin on about five per cent of the basin's land area. Angola, Central African Republic and Congo each make up between seven and ten per cent of the basin's area, however all have sparse populations in their basin areas ranging from between eight and eleven people per km<sup>2</sup>.

### Precipitation

At around 1 100 mm/yr, Tanzania's portion of the basin has the lowest mean annual rainfall of any of the basin's countries. Congo has the highest in the basin at almost 1 700 mm/yr. Some parts of the Republic of the Congo and DRC receive an average of over 2 000 mm/yr (Figure 2.2.2). Because of the large area and heavy rainfall the DRC receives about two-thirds of all the rain in the basin and contributes about the same proportion of the basin's total runoff (Figure 2.2.3). Rainfall is seasonal in parts of the basin, however its size ensures that there is always some part of the watershed receiving heavy rains. At the mouth of the river these variations are averaged out to produce a relatively consistent flow with small peaks in November and May (Laraque and others 2001, Dai and Trenberth 2002).

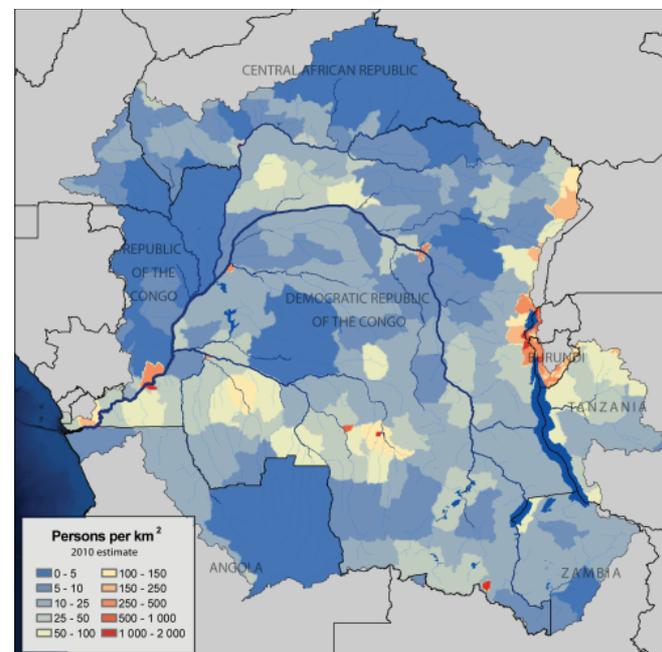


Figure 2.2.1 Congo Basin population density 2010

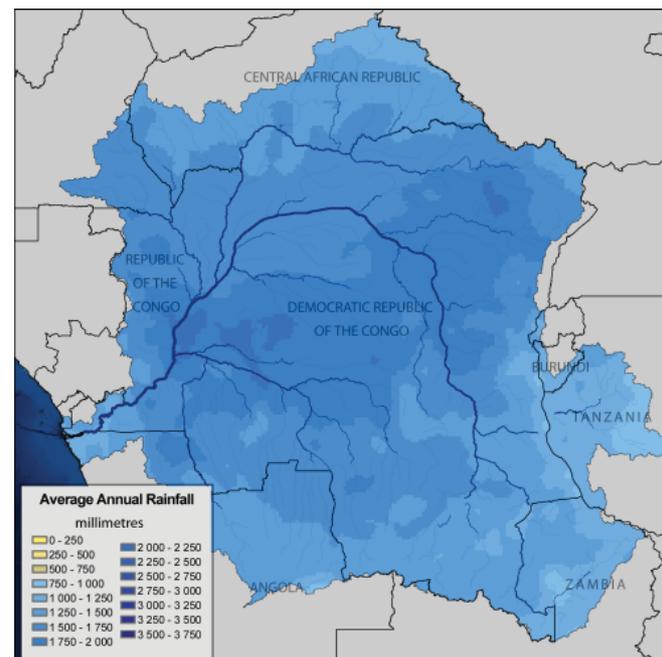


Figure 2.2.2 Congo Basin average annual rainfall

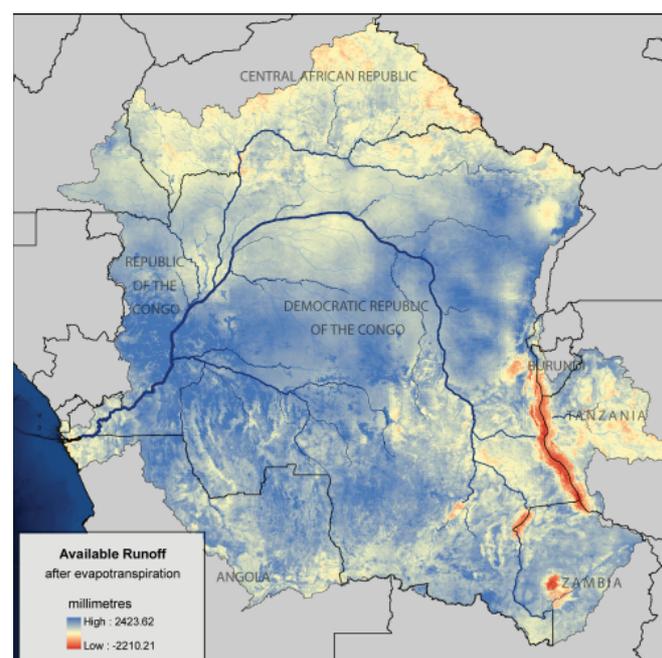
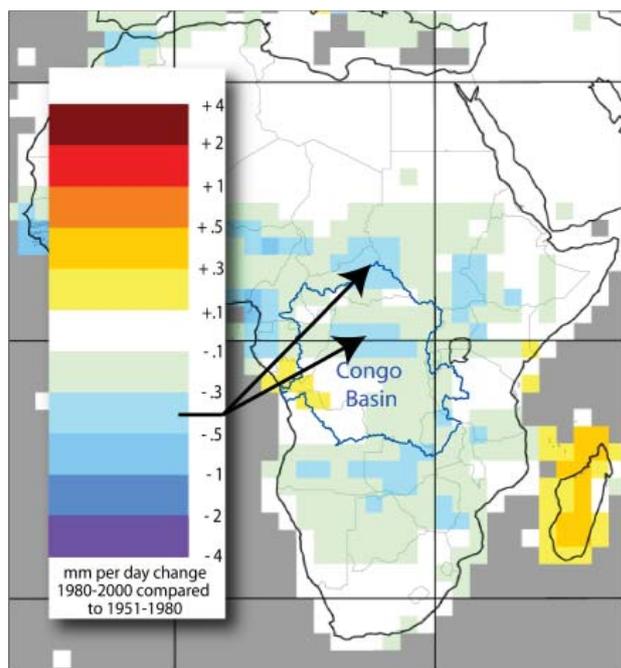


Figure 2.2.3 Congo Basin modeled available runoff

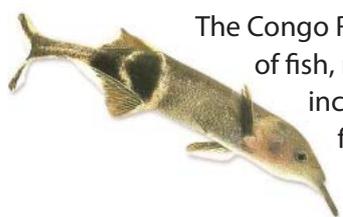
## Transport

More than 1 000 km of the Congo River are navigable by large commercial vessels (UNEP 2008). Much of the basin's economic activity relies on these waterways for transport of principally timber, agricultural products, fuel and minerals. The three main routes converge at Kinshasa from Kisangani, Bangui (on the Ubangi) and Ilebo (on the Kasai) (Figure 2.2.4). The absence of roads in many parts of the basin makes these waterways crucial for transport and communication. Problems of low water levels, particularly in the Ubangi have increasingly interrupted navigation since the 1970s (Ndala 2009). This is consistent with precipitation trends during the same period, which show a decrease in average annual precipitation between 1970 and 2000 (NASA 2010) (Figure 2.2.5). Ironically, one of the proposed responses is an inter-basin transfer of water from the Congo Basin to the Lake Chad Basin. Proponents of the project cite "permanent navigability of the Ubangi River," as one of the benefits of a project that would include a dam on the Ubangi (near Palambo, CAR). The expectation is that the dam would even out the flow of the river and thus reduce the number of days that it is too low for large vessels to navigate (Musa 2008).

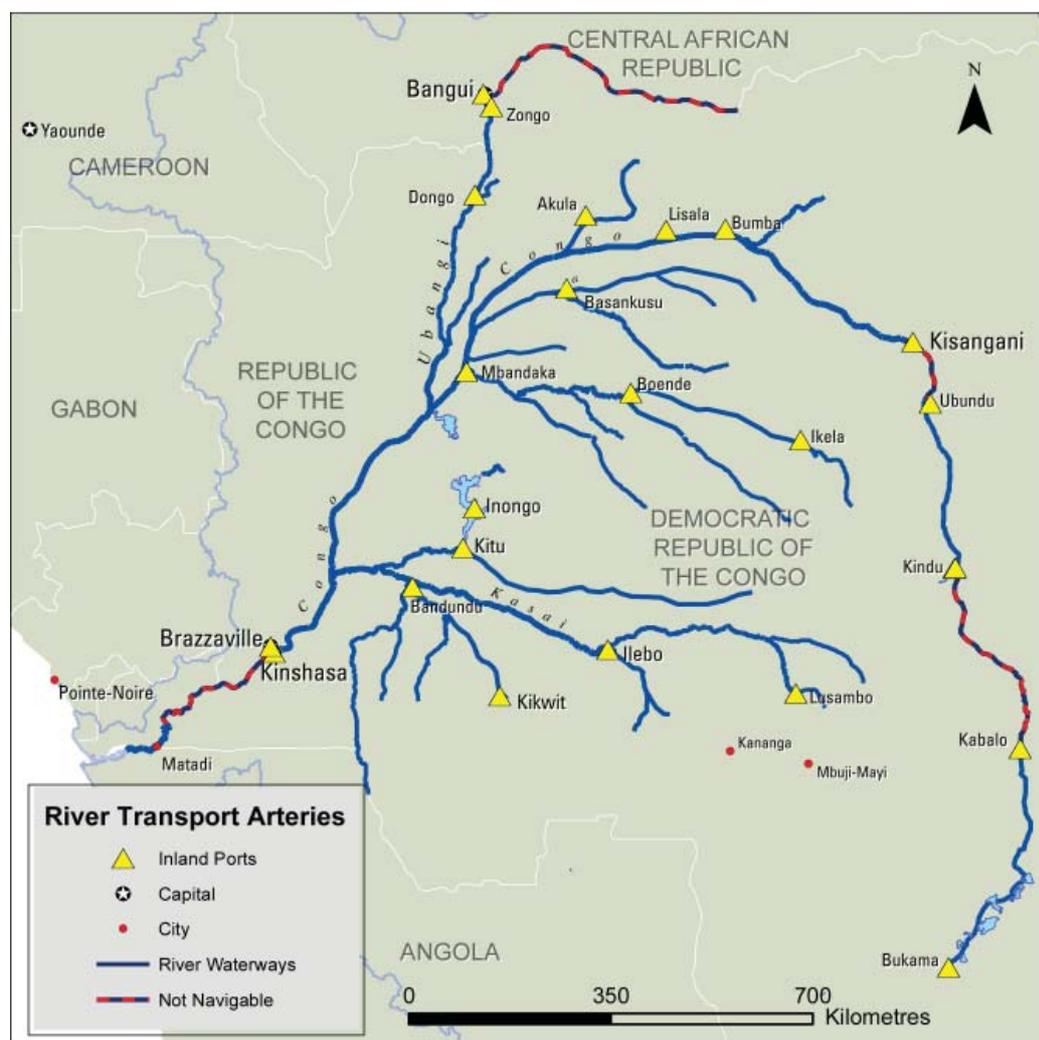


**Figure 2.2.5: Precipitation data from NASA's Goddard Institute for Space Studies shows that there was a decrease in rainfall over parts of the Congo Basin between the period 1951-1980 compared to the period 1980-2000**

## The Fisheries



The Congo River is home to nearly 800 species of fish, many of them endemic to the river, including the exotic lungfish and elephant fish (National Geographic 2010). The fisheries of the Congo River system's 33 000 km of streams provide high-quality protein for millions of people (Upper Congo Fishes Project n.d.). For many, it is a source of income as well (Bene and others 2009). Traditional fishing methods are generally used, including gillnets, seine nets, handlines and non-motorized canoes. However the use of a poisoning technique, utilizing toxic plants and even dynamite fishing have been reported (FAO 2001, Kashema 2006).



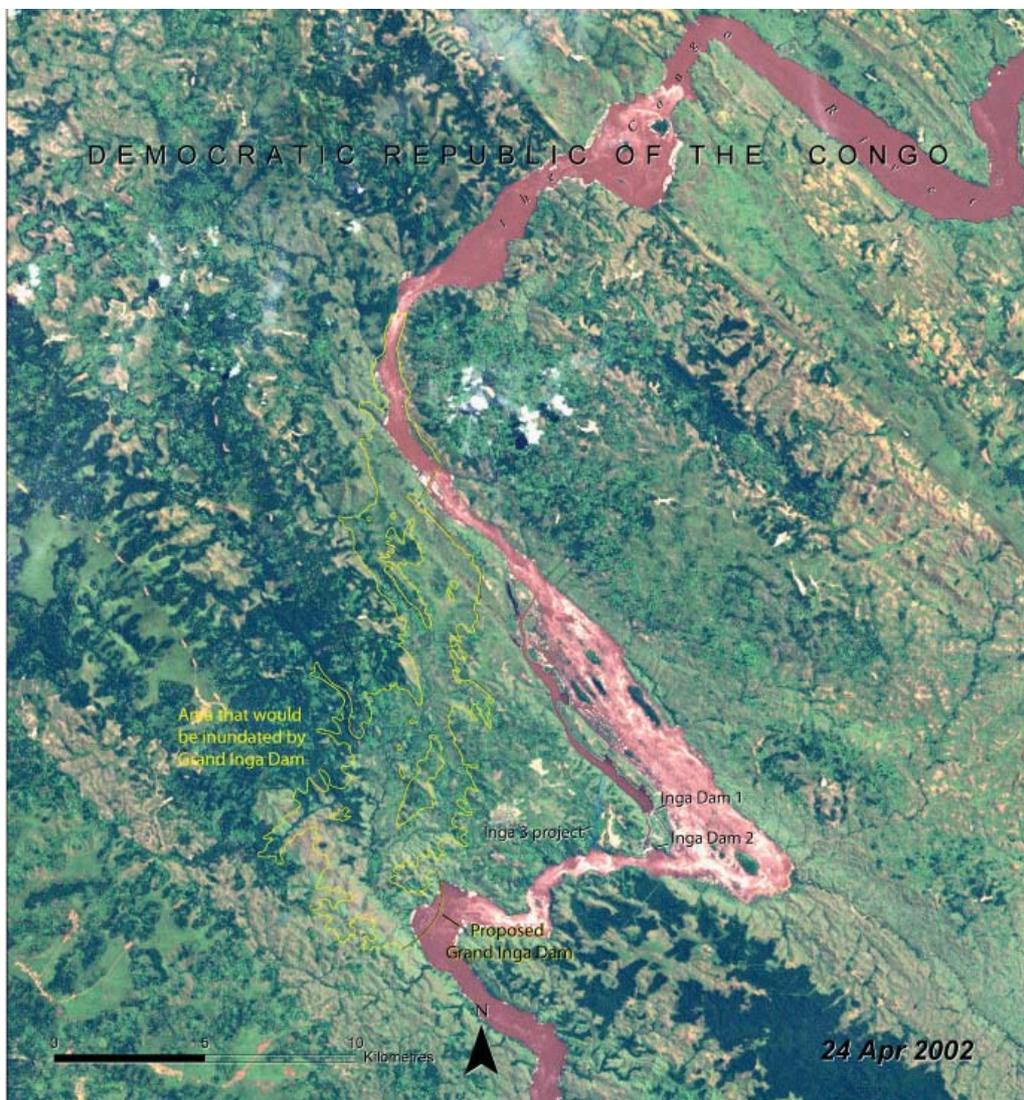
**Figure 2.2.4: The absence of roads in many parts of the Congo Basin makes transport on the river's navigable waterways crucial for economic activity**

## Water Quality

Water quality is an issue in some cities along the river as well as some stretches of the navigable river and at the coast where there are oil refining facilities. Some of this pollution is also linked to transport activities and industrial facilities (FAO n.d.). Environmental impact assessments are not required for activities other than mining in the Democratic Republic of the Congo. DRC law requires an Environmental Impact Study, Mitigation and Rehabilitation Plan and an Environmental Management Plan for mining activities (SADC 2007); nevertheless, World Bank reports state that "Environmental impacts of mining operations in DRC are substantial and growing worse" (World Bank 2008). Katanga Province is the headwaters area of the Congo River and is also where much of the DRC's copper and cobalt are mined. Most of the mining areas in DRC have hydrological connections to the Congo River (Kirongozi 2008). Water quality concerns associated with copper mines include the release of processing chemicals, heavy metals and acids from tailings as well as erosion and sedimentation due to soil and rock disturbances caused by mining and the construction of associated infrastructure.

## Agriculture

Transportation infrastructure is a greater factor in limiting agricultural development in the Congo Basin than is water; nevertheless, the amount of irrigated land within the basin is a very small fraction of the potential for irrigation based on water availability (FAO 1997). The potential for expanded lowland rice production within the basin is significant but is constrained by limited irrigation facilities and poor maintenance, among other things (FAO 2002).



**Figure 2.2.6: The reservoir of the proposed Grand Inga Dam would submerge roughly 55 km<sup>2</sup> of land if the project were to go forward as originally designed**

potential but fell into disrepair over the years. A project to rehabilitate Inga 1 and Inga 2 is under way at a cost of over US\$500 million (IR n.d.a).

There are plans for additional development at the Inga Falls site (Figure 2.2.6). Inga 3 would draw water from the existing reservoir used by the Inga 1 and Inga 2 dams through eight 6 770 m tunnels—each tunnel driving two hydropower turbines (IR n.d.b). This phase is expected to cost approximately US\$5 000 million. However, Inga 3 would be dwarfed in cost and scale, if the proposed Grand Inga Dam and related infrastructure are built at an estimated cost of US\$50 000 million (IR n.d.c). Grand Inga would generate 44 000 MW of electricity— enough to power the entire continent of Africa.

The value of cheap energy for development is undeniable. However, while the Inga 3 project qualifies for carbon-offset credits under the Kyoto Protocol (according to some involved in the project), and hydropower is relatively “green” from an environmental perspective, the Inga projects, and in particular Grand Inga, are not without serious unresolved questions regarding environmental impact and sustainability (Showers 2009, Counter Balance 2009). Serious and thorough environmental assessments and feasibility studies for Inga 3 and Grand Inga will be needed to avoid the unintended consequences that have plagued other large dam projects in Africa (Davies and others 2000, DeGeorges and Reilly 2006).

### Inga Dams and the Grand Inga Scheme

Interest in developing hydropower at Inga Falls in the Democratic Republic of the Congo dates back to the early 20th century when the high potential for generating electricity was first recognized (Showers 2009). The potential is created by a 102 m drop in the river’s bed along just 15 km of its length. The Inga 1 Dam (commissioned in 1972) and the Inga 2 Dam (commissioned in 1983) realized some of that

One of the project’s controversial aspects is the proposed transmission system, which would supply power to a host of countries on the continent and potentially Europe as well (EIA 2002) (Figure 2.2.7). Critics have voiced concerns about the transmission line’s environmental footprint and point out that in spite of its projected cost of US\$40 000 million, it will not bring electricity to the majority of local people who are not already on the electrical grid (IR n.d.a).

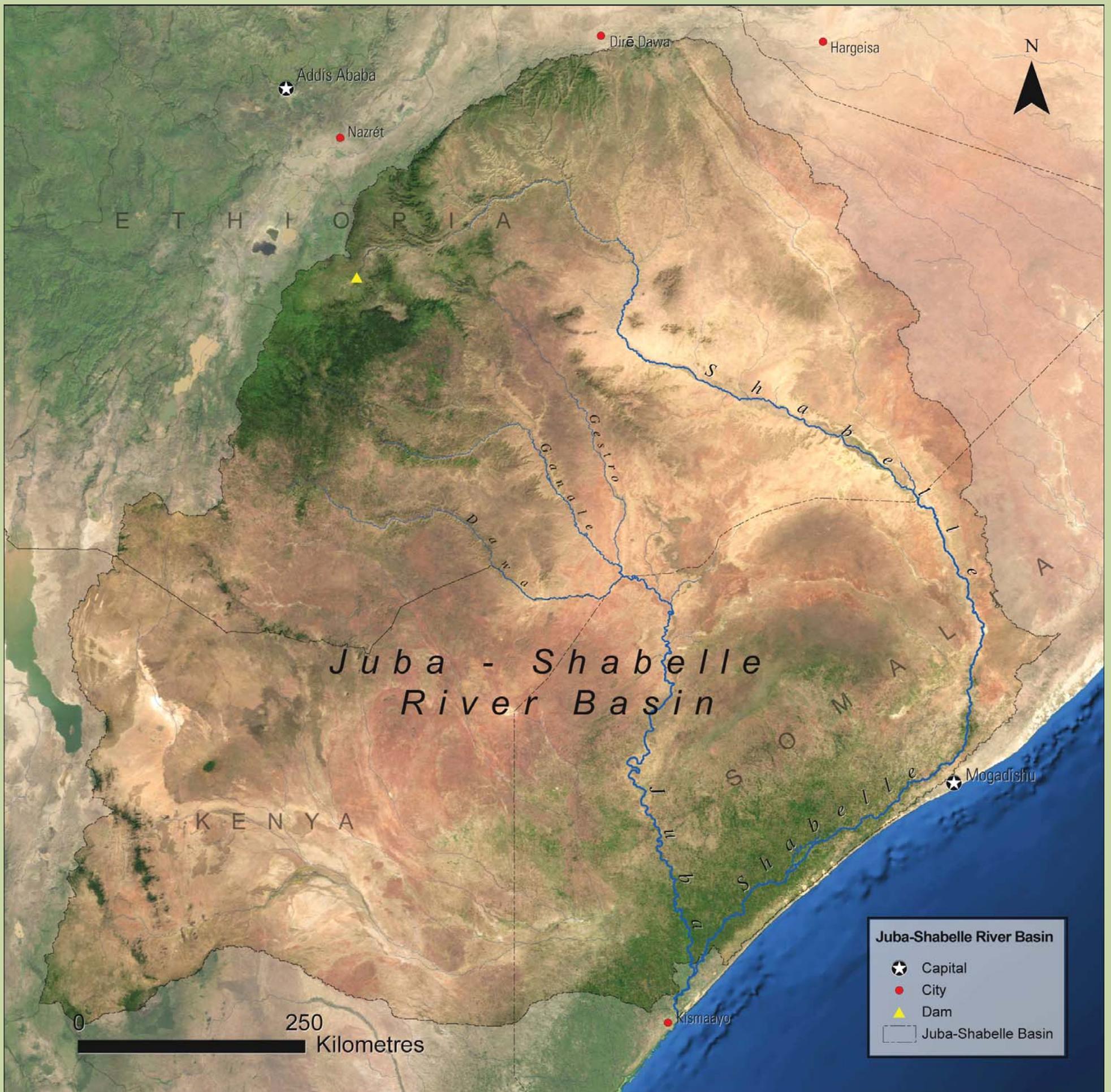
**Figure 2.2.7: Proposed transmission system (Source: IR 2008)**



# Juba Shabelle Basin



Both the Juba and the Shabelle originate in the southeastern portion of the Ethiopian Highlands at over 3 000 m above sea level. The Juba has the smaller catchment area but receives heavier rainfall and has considerably higher runoff near its headwaters.



*In most years, the Shabelle's discharge terminates in wetlands short of its confluence with the Juba*

Both rivers lose discharge as they progress downstream due to a lack of rainfall in downstream areas, high evaporation and significant infiltration and withdrawals (Thiemig 2009). In most years, the Shabelle's discharge terminates in wetlands, short of its confluence with the Juba (FAO 2000).

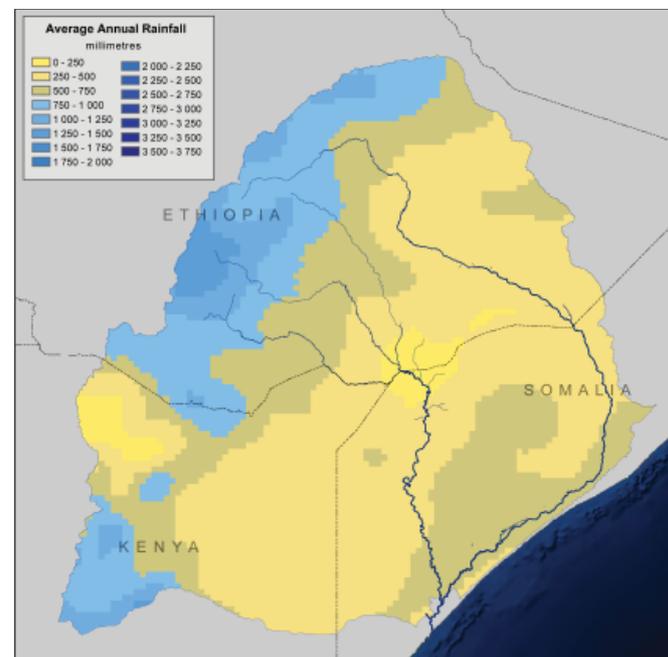
**Precipitation**

The basin's rainfall comes in two rainy seasons with less pronounced dry seasons in the higher areas of Ethiopia than in lower areas throughout the rest of the basin. The primary rains occur from April to June delivering around 60 per cent of the annual rain. Lesser rains in October and November bring around one quarter of the year's precipitation (Artan and others 2007). Total annual rainfall in some areas of the Juba headwaters is over 1 400 mm. Much of the rest of the basin is arid or semi-arid and a lot of the lowland part of the basin receives less than 500 mm of rain annually and some parts as little as 200 mm (Figure 2.3.1, Figure 2.3.2). High temperatures, along with the limited rainfall, further reduce the contribution of most of the basin to the Shabelle-Juba River system. Ethiopia contributes the vast majority of the two rivers' flows, while Kenya has little influence and Somalia's portion of the basin has a negative net impact on the two rivers' water budget.

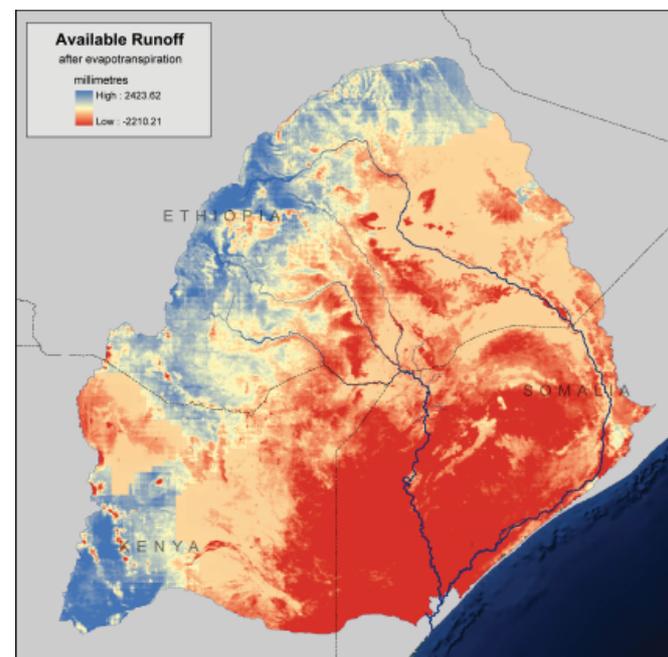
Agriculture is by far the largest water-user in most downstream areas, but relies predominantly on surface water (FAO 2005). Rainfall varies dramatically from year to year throughout the basin, however, causing severe droughts every seven to ten years (FAO 2005). This is catastrophic for rain-fed agriculture, which has increased in Somalia in recent decades as irrigation infrastructure has fallen into disrepair or been destroyed (FAO 2005). Somalia's heavy reliance on the Juba and Shabelle Rivers makes water development in Ethiopia, such as the Melka Wak Dam on the Shabelle, of great concern to Somalia.

**Population**

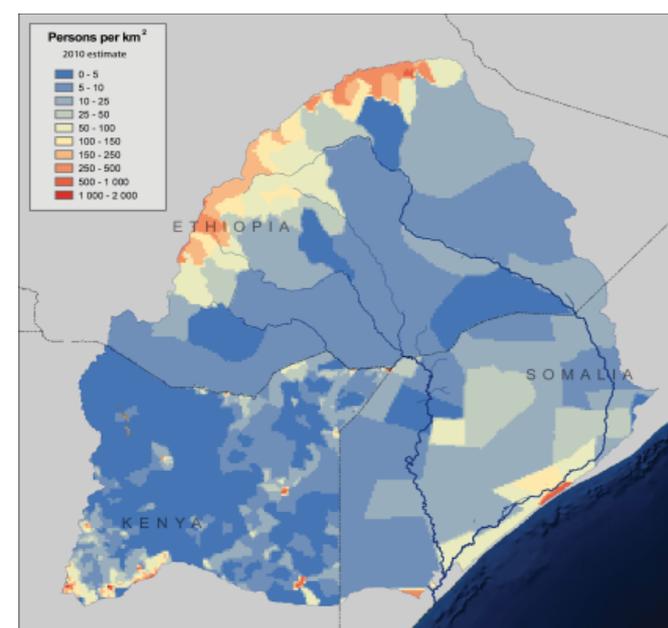
Approximately 13 million of the basin's roughly 20 million people live in the Ethiopian part of the basin. Kenya's quarter of the basin has a population of roughly 2.5 million. Somalia is estimated to have between 3.5 and 5.5 million people in its part of the basin (Figure 2.3.3).



**Figure 2.3.1 Juba-Shabelle River Basin average annual rainfall**



**Figure 2.3.2 Juba-Shabelle River Basin modeled available runoff**

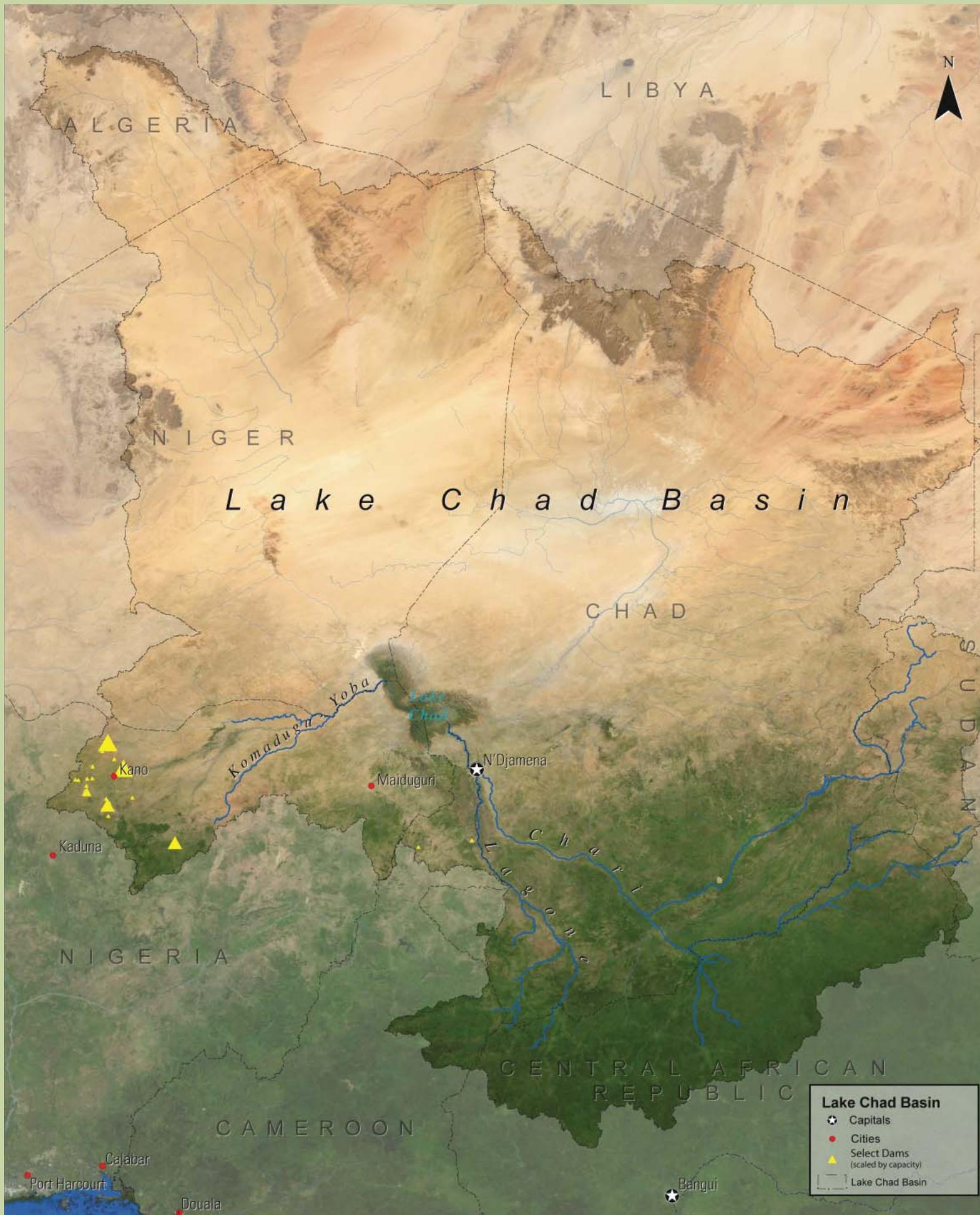


**Figure 2.3.3 Juba-Shabelle River Basin population density 2010**

# Lake Chad Basin



The watershed basin of Lake Chad makes up just over eight per cent of the surface area of Africa, and falls across the boundaries of eight countries—Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria and Sudan.



*Lake Chad is among the largest freshwater reservoirs in the Sahel*

It stretches across a range of landscapes north to south, from the barren core of the Sahara Desert in the north to heavily wooded savanna areas of northern Cameroon and the Central African Republic. Rainfall, vegetation, population and economic activity are all concentrated in the southern half of the basin with the lake itself falling along the transition from savannah to desert in the heart of the Sahel. The Chari, the Logone and the Komadougou Yobé rivers carry nearly all of the water in the basin. Nevertheless, even with no outlet to the sea, the basin's salinity remains low. Research has shown that the salts are controlled by seepage into the groundwater and to a lesser degree by sedimentation (Roche 1977, Isiorho and others 1996). The lake is among the largest freshwater reservoirs in the Sahel making it a focal point of human activity (Musa 2008). This is especially so for the more than three million people (SEDAC 2010) living within 200 km of the lake, many of whom make their living by farming, fishing and tending livestock (Musa 2008).

**Population**

Based on estimates of the 2010 population (SEDAC 2010), around 46 million people live within the larger Lake Chad basin, with most concentrated in the watershed's southwest corner (SEDAC 2010) (Figure 2.4.1). Nigeria, which makes up 7.5 per cent of the basin's area, is home to 26 million of the basin's people—well over half. Chad is the second-most populated with ten million of its people living in the basin, and Niger is third, with just under three million (SEDAC 2010). All three countries have had high estimated population growth rates over the past five years, ranging from 2.3 per cent annually in Nigeria to 3.5 per cent annually in Niger (UN-WPP 2006). Sudan and Cameroon each have around 2.5 million people living within the Chad Basin (SEDAC 2010).

**Precipitation**

Despite Chad's large size within the basin (46 per cent of its area) and the fact that it receives roughly 43 per cent of the basin's rainfall (Figure 2.4.2), it contributes well less than a third of the water balance, due to high evapotranspiration rates. Nigeria, with only 7.5 per cent of the basin's area, also contributes roughly 30 per cent of the basin's water balance (Senay and others 2010). Around a quarter of the total basin's runoff comes from the Central African Republic portion of the basin (Figure 2.4.3). While Niger makes up over one-quarter of the basin, it only receives 5.5 per cent of its precipitation and loses more than that to evapotranspiration, thus having a negative impact on the basin's water balance.

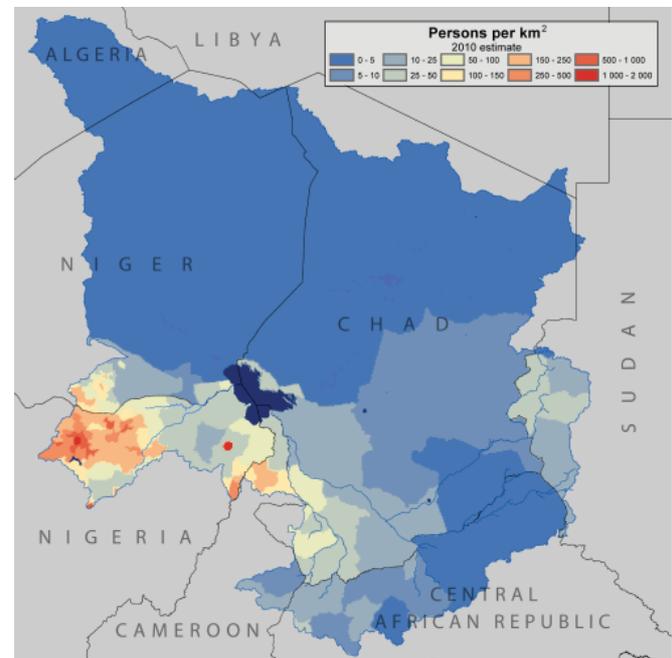


Figure 2.4.1 Lake Chad Basin population density 2010

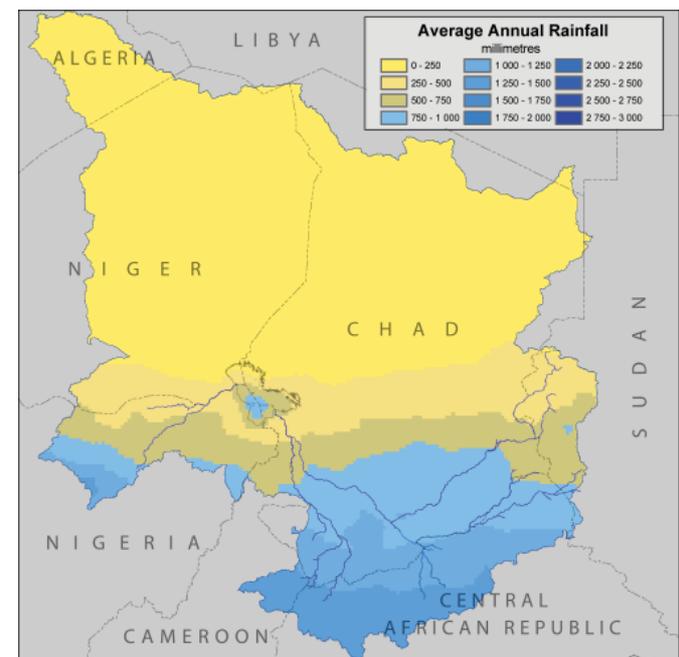


Figure 2.4.2 Lake Chad Basin average annual rainfall

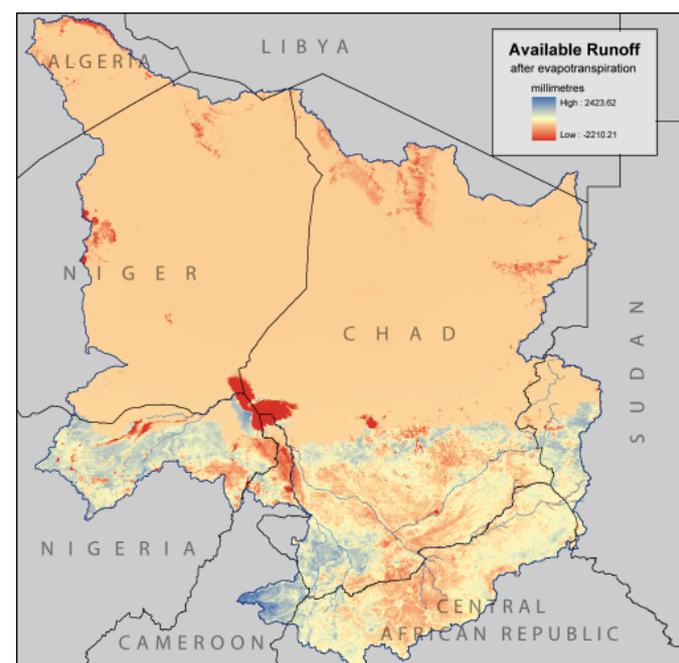


Figure 2.4.3 Lake Chad Basin average annual runoff

## Lake Chad's Variability

Precipitation is highly variable across the Lake Chad watershed seasonally, from year to year, and over periods of several decades. This variability coupled with the shallowness of the lake makes its surface extent almost equally variable. The series of remote sensing images spanning the past 50 years shows the scale and pace of changes that have taken place (Figure 2.4.7, page 50-51). Between the early 1960s and the mid-1980s, surface area generally declined from a maximum of more than 25 000 km<sup>2</sup> to as small as 1 350 km<sup>2</sup>. Determining long-term trends in surface area or lake levels (Figure 2.4.4 and 2.4.5) and attributing this change to specific causes has been complicated by this background of constant change. Nevertheless, some understanding of the trends and their causes is developing among scientists studying the lake.

It is well established that the overwhelming majority (85 to 90 per cent) of the water in the lake comes from the Chari-Logone River system (Figure 2.4.8, see page 52), with almost the entire remaining fraction derived from the Komadougou Yobé River and from direct rainfall (Coe and Foley 2001, Nihoul and others 2003). The discharge of the Chari-Logone system has decreased by nearly 75 per cent since the mid-1960s, due to drought and diversion (GIWA 2004). While some studies have indicated that

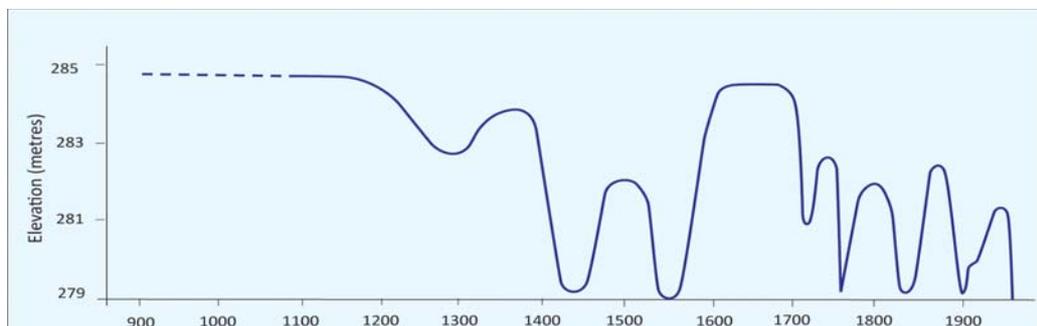


Figure 2.4.4: Long-term historical water levels of Lake Chad (Source: Olivry and others 1996)

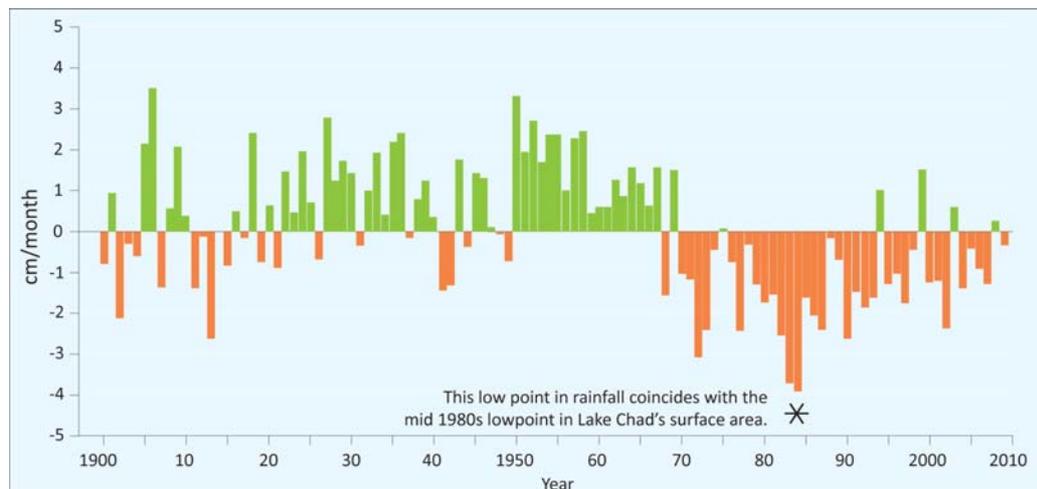
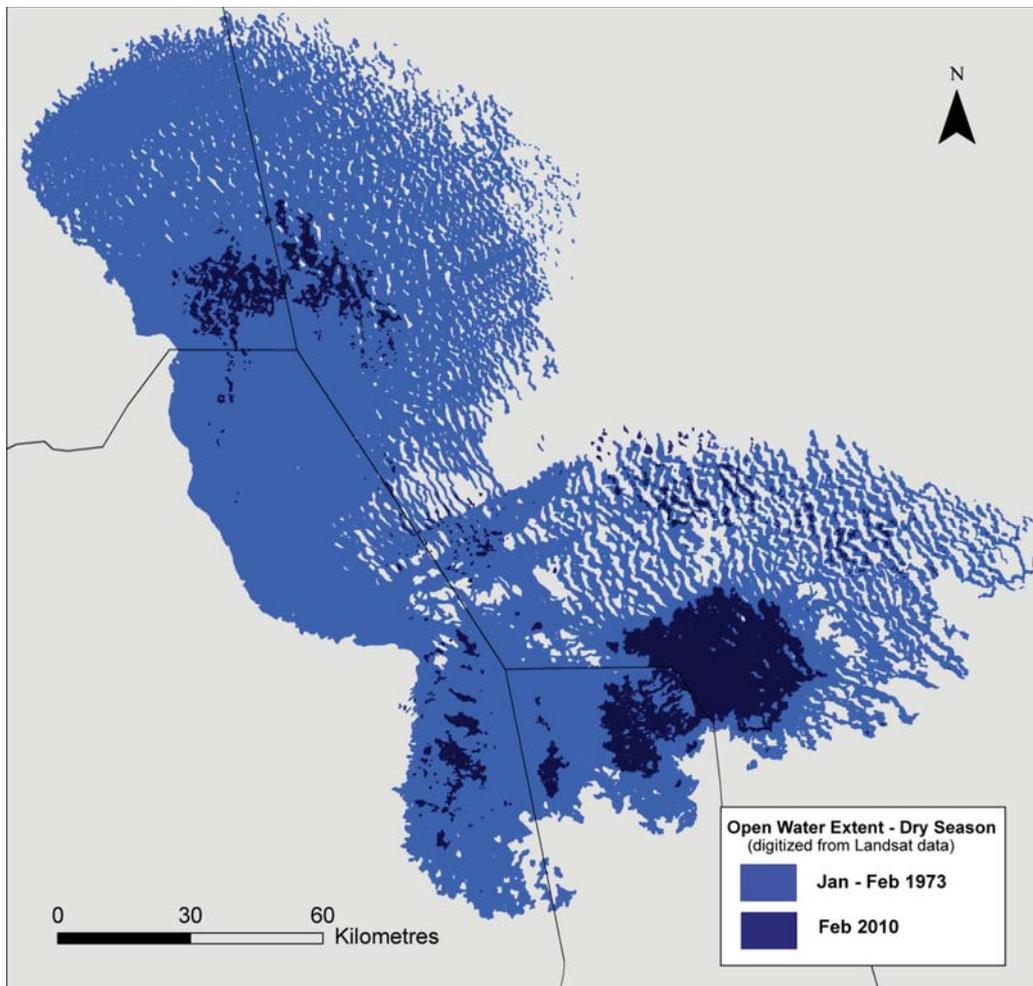


Figure 2.4.5: June to October, mean Sahel precipitation anomalies, 1900-2009 (Sources: University of Washington 2009)



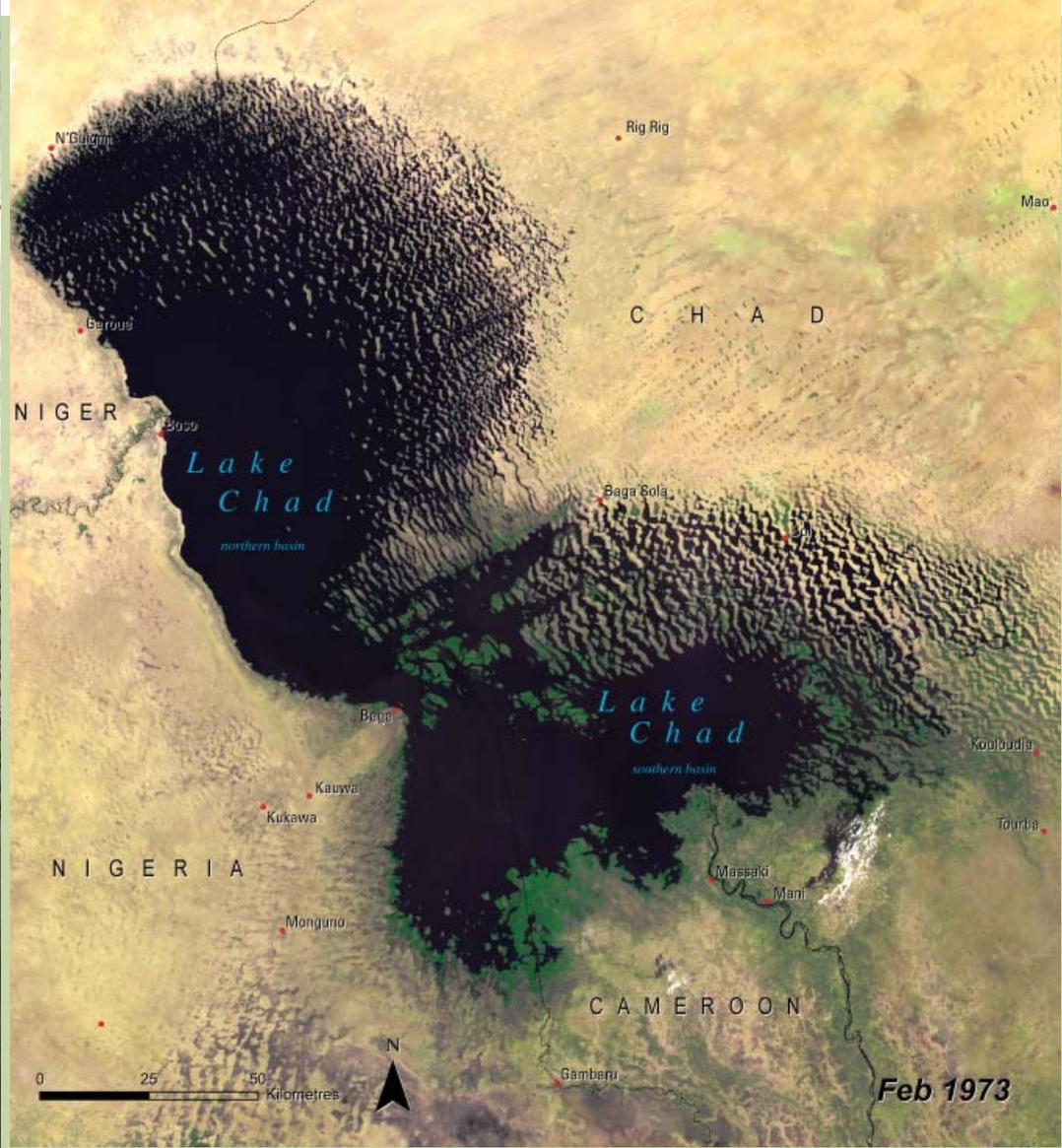
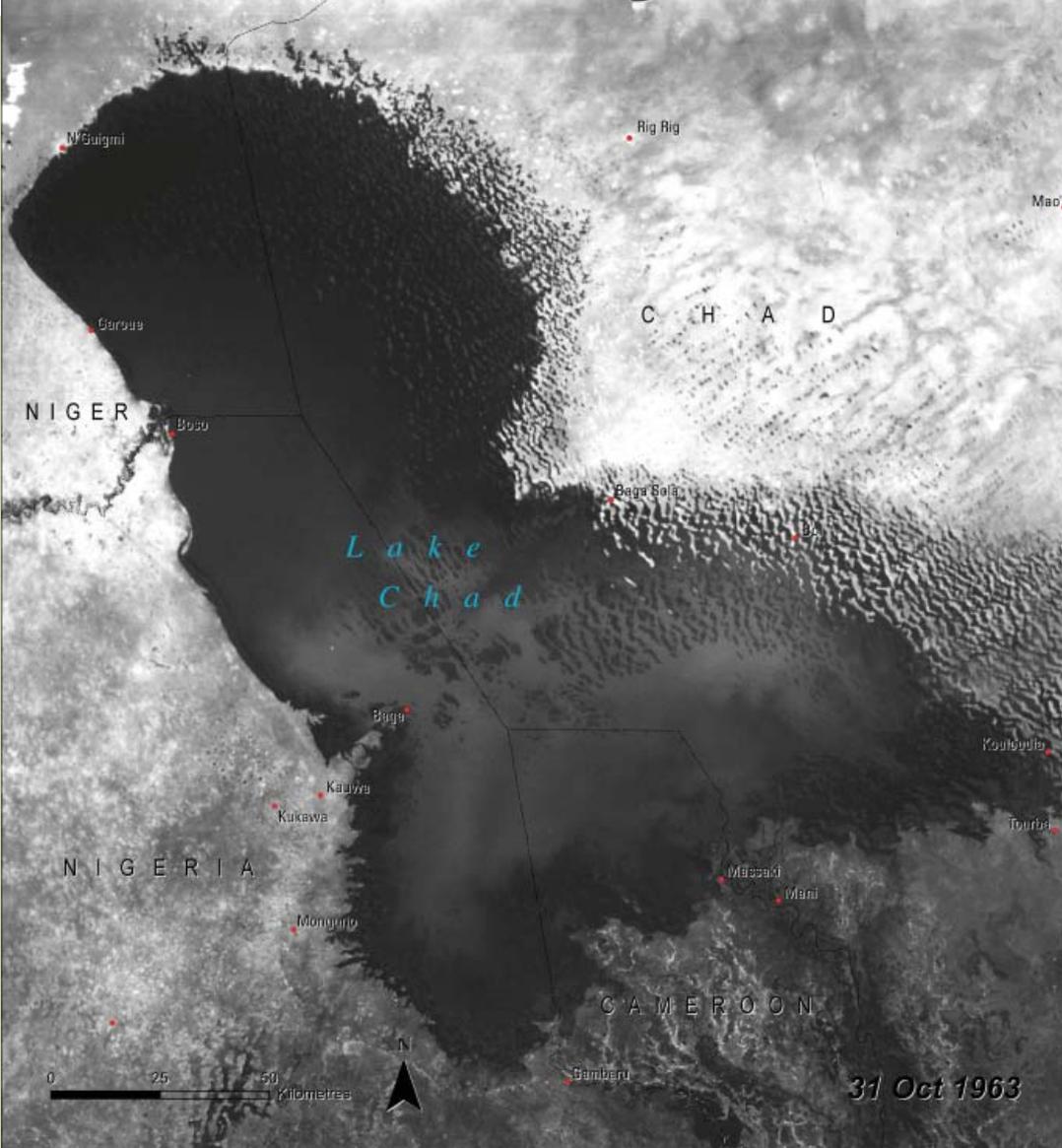


**Figure 2.4.6: Approximate extent of open water in Lake Chad digitized from Landsat images, 1973-2010**

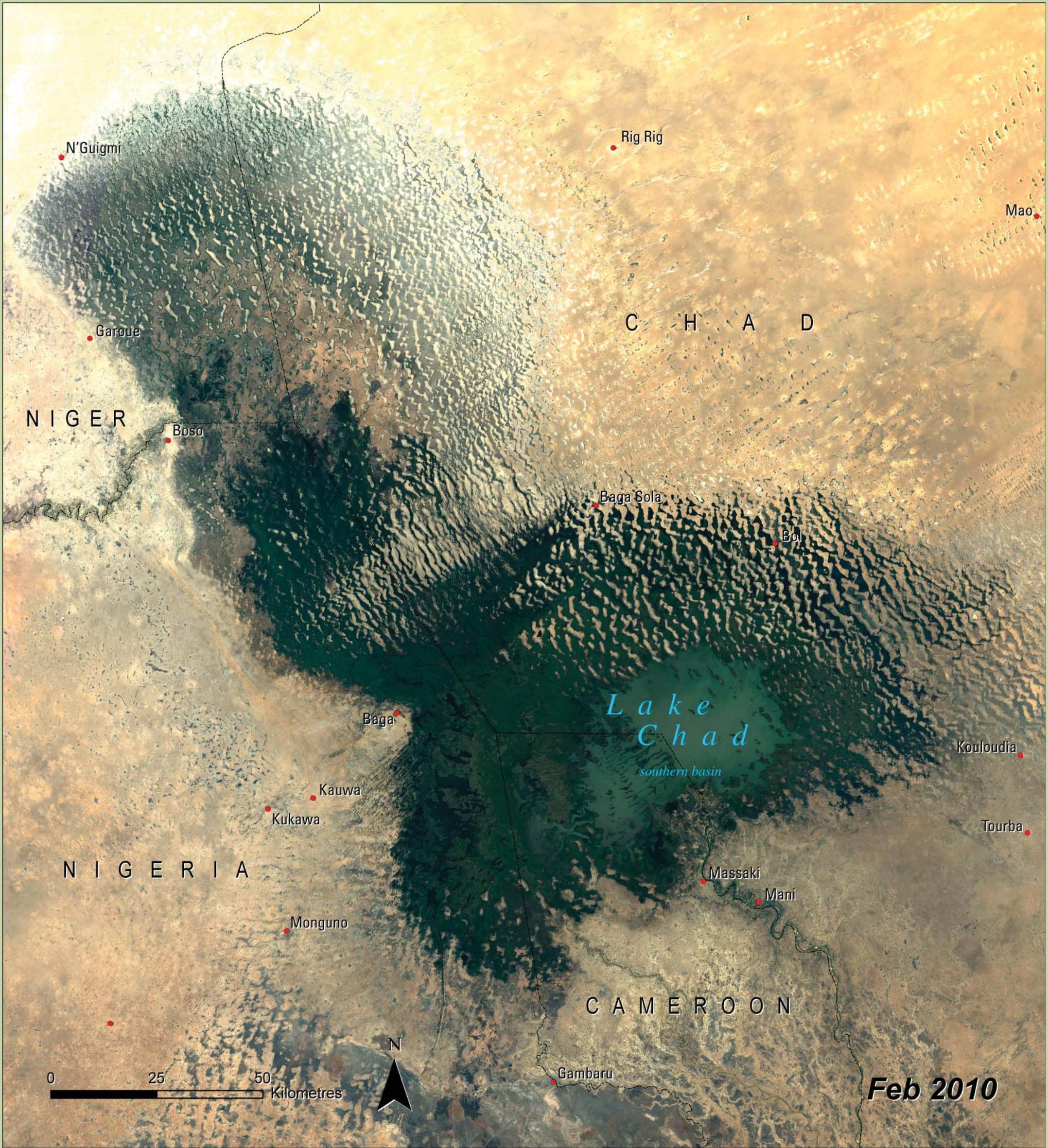
irrigation that draws water from the Chari-Logone system has played a major role in the lake's declining size since the early 1970s (Coe and Foley 2001), the relative importance of irrigation is disputed (Lemoalle 2008, Nihoul and others 2003). Nevertheless, population is growing within the Chari-Logone Basin and as a result so is the demand for water (GIWA 2004), which will likely increase the importance of diversion in the Lake Chad water budget.

It is quite clear, however, that a decline in average rainfall following 1970 was a central cause of the drop in the lake level and areal extent during the same time frame (Lemoalle and others 2008) (Figure 2.4.6). The droughts of the 1970s and 1980s have in turn been linked to naturally occurring variation in Atlantic sea-surface temperatures (Shanahan and others 2009, Zhang and Delworth 2006, Giannini and others 2003). Recent research suggests that current patterns of drought driven by these variations are not anomalous, with evidence of much more extreme droughts across the Sahel as recently as 200-300 years ago and patterns of similar droughts extending back at least a few thousand years. Figure 2.4.5 raises the possibility that a drought more severe than the ones in the 1970s and 1980s could occur in the foreseeable future. In addition, it is suggested that global warming would likely make these droughts still more severe (Shanahan and others 2009).





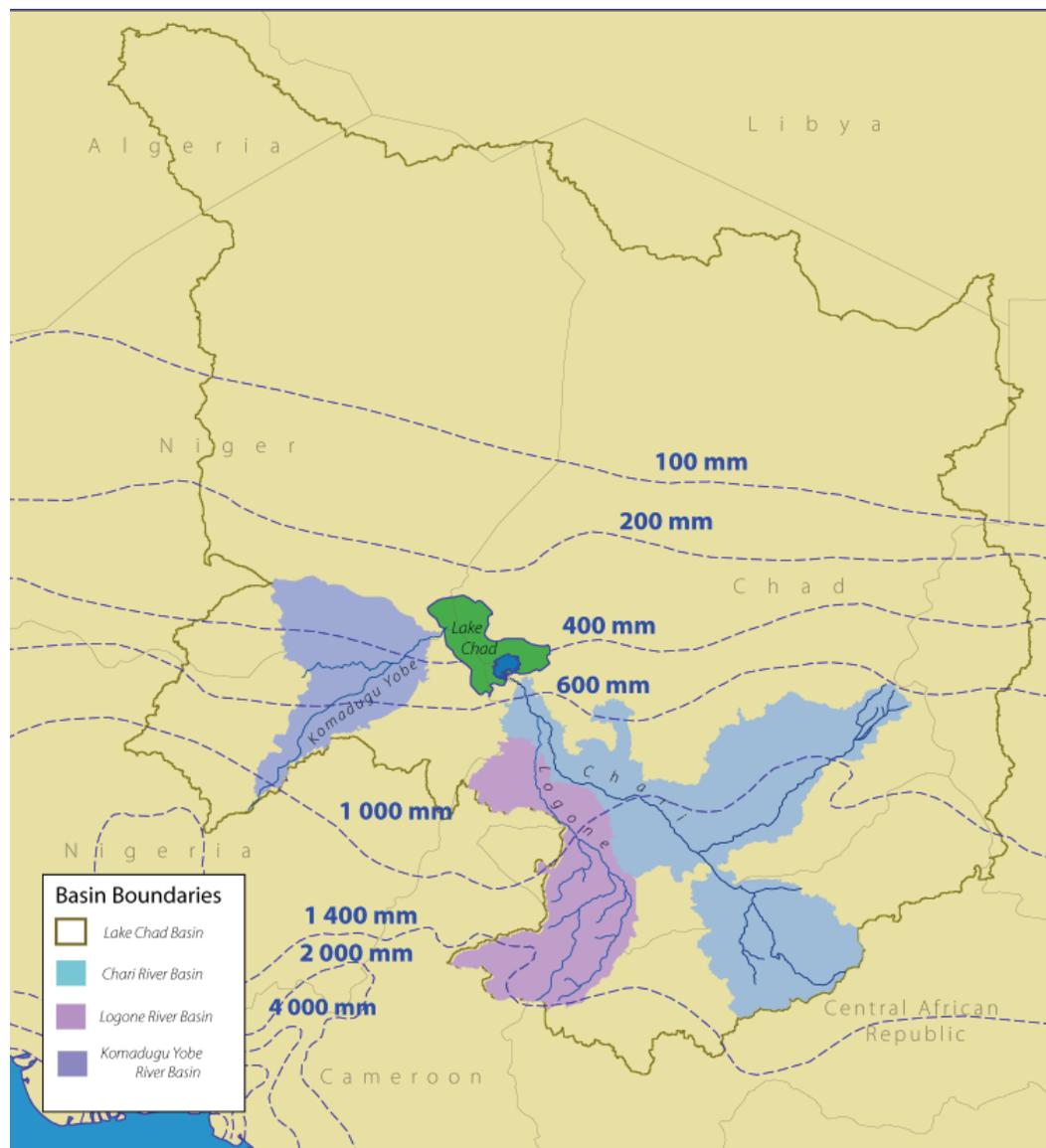
**Figure 2.4.7:** While Lake Chad's surface area fluctuates considerably with the seasonal rains, these dry-season images of Lake Chad show the long-term trend since the 1960s. Changes in rainfall during this period (Figure 2.4.5) have been a major factor as has diversion for irrigation (Coe and Foley 2001)



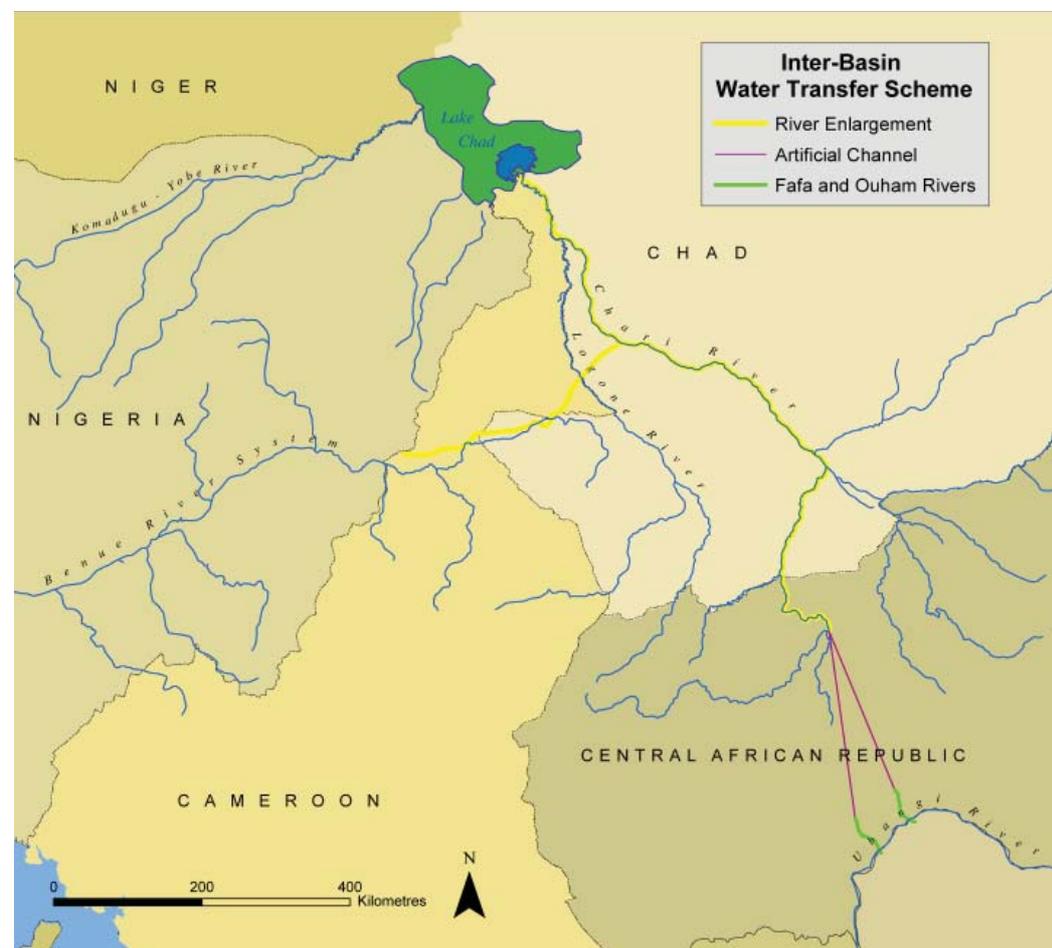
Decreased flow in the Chari-Logone system has dramatically decreased water supply to human and natural systems downstream (FAO 2009). The rate of change in the ecosystem has outpaced the rate at which the natural flora and fauna are able to respond and adapt (FAO 2009). The decline in Lake Chad has forced fishing communities to migrate to follow the receding lake waters (GIWA 2004). Reduced inundation of the Yaéré and Waza-Logone floodplains has had a negative impact on farming (GIWA 2004) and reduced the quality and area of dry-season grazing (IUCN 2003b). Wells must be dug deeper to reach the lower water table (GIWA 2004). The impact of drought and reduced lake area has already been profound for people living close to the lake and impacts extend to a lesser extent to the over 35 million people who live in the larger Chad Basin (GIWA 2004).

One response to the shortage of surface water has been increasing groundwater use. The Quaternary aquifer underlying the Lake Chad basin is the major groundwater source for the region (Ngatcha and others 2008). There is a lack of hydrogeological datasets for the area, which are needed for sustainable use of these groundwater assets (Ngatcha and others 2008). One recent study suggests that water levels in the Quaternary aquifer declined in response to the decrease in rainfall during the second half of the last century (Boromina 2008). This probability highlights the need for improved availability and completeness of hydrogeological datasets for policy makers looking for appropriate responses to the Lake Chad Basin's diminishing water resources.

Another proposed response that would directly address the lowering lake levels is the transfer of water from outside the Lake Chad Basin (see also page 42). A scheme to pump water from the Ubangi River to restore the Lake Chad and Chari River system was developed in the late 1980s (FAO 2009) (Figure 2.4.9). A dam would be built on the Ubangi at Palambo CAR from which water would then be pumped into the Fafa and Ouham Rivers. From there it would flow through a 1 350 km man-made channel to reach the Chari River and ultimately Lake Chad (FAO 2009). In November 2009, a US\$6 million feasibility study was begun by a Canadian engineering firm on behalf of the Lake Chad Basin Commission. It is to be completed by late 2011 (CIMA n.d.).



**Figure 2.4.8: Rainfall averages only around 400 mm/yr at Lake Chad, but increases to the south where most of the Lake's inflow comes from—primarily from the Chari, Logone and Komadougou-Yobé Basins**



**Figure 2.4.9: A proposed inter-basin transfer project would take water from the Ubangi River in the Congo River Basin and transfer it to the Lake Chad Basin**



**Figure 2.4.10: Damming of the Logone River in the 1970s coinciding with a period of drought reduced overbank flooding and disrupted local livelihoods on the Waza Logone Floodplain. Managed releases from the dam beginning in the 1990s restored some of the natural flooding, bringing improved grazing and return of other valuable ecosystem functions.**

### The Waza Logone Floodplain

The Waza Logone floodplain in northern Cameroon is a highly productive seasonal wetland with great biodiversity importance (IUCN 2004). It also provides livelihoods to approximately 135 000 people through recession agriculture, fishing, livestock and natural products and services such as honey, medicines and building materials (IUCN 2004). The high productivity and many of the ecosystem goods and services depend on overbank flooding from the rivers that feed into the wetland—primarily the Logone River but also the seasonal Tsanaga, Boula and Vrick Rivers. Many of these ecosystem services were lost on large parts of the floodplain following the construction of the Mago Dam and associated rice-irrigation schemes in the 1950s and late 1970s, which coincided with a period of below-average rainfall (Loth 2004). The drought, along with regulation of the Logone River for irrigation, greatly reduced natural flooding, which led to serious environmental damage and disrupted the lives of many local people who relied on the flooding for their livelihoods (Loth 2004).

The satellite image from late 1986 (Figure 2.4.10) flooding season shows little standing water and minimum wetland vegetation in the area just southwest of Waza National Park. In the 1990s, the

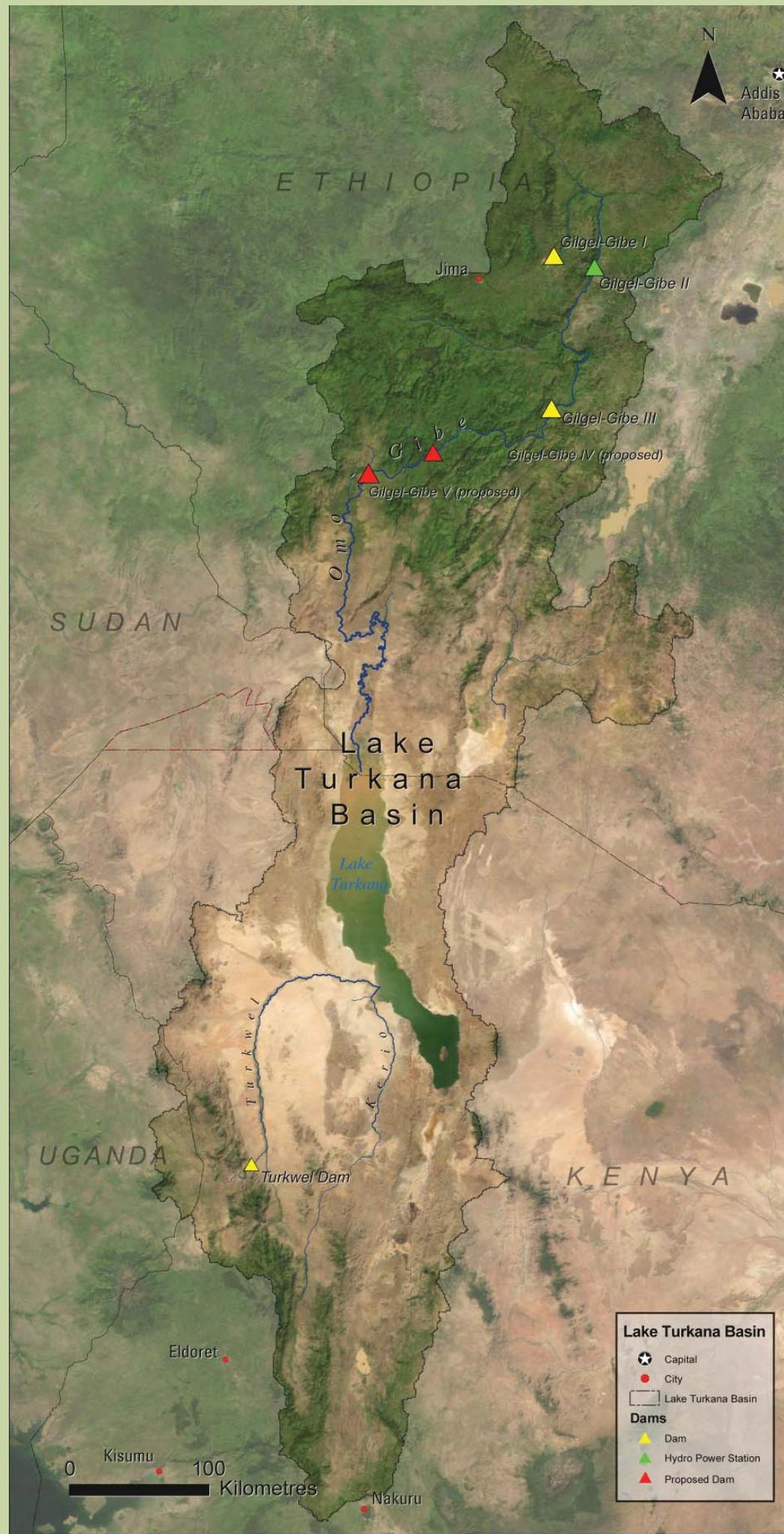


management strategy of the Logone's flow was broadened to consider the viability of downstream resources (Loth 2004). Some channels that had been modified for the rice schemes were opened to allow water to flood roughly 200 km<sup>2</sup> (IUCN 2004). The integrated management of the floodplain's natural resources has allowed the return of some natural grasses that had been lost, enhanced productivity, increased bird numbers and improved grazing (Scholte 2005). Figure 2.4.10 from the 2005 and 2006 flooding seasons shows adequate flooding in the area southwest of Waza National Park along with heavy wetland vegetation.

# Lake Turkana Basin

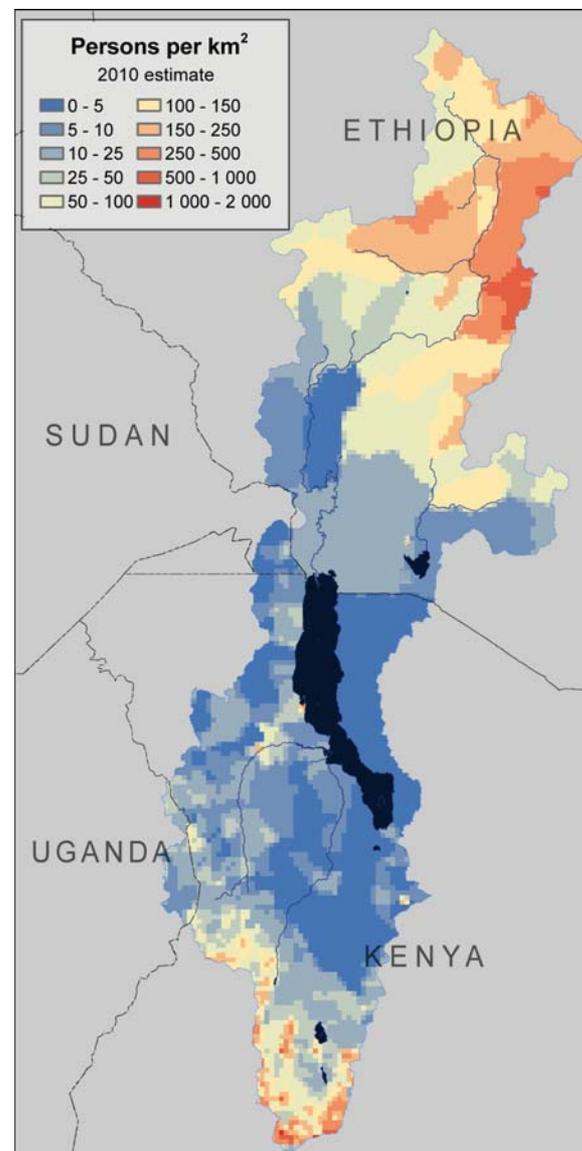


Although the Lake Turkana Basin occupies parts of four countries, 98 per cent of its area lies within just two of them. More than half (52 per cent) is in Ethiopia, where almost three-quarters of the basin's rain falls.



**Lake Turkana  
is the largest  
desert lake in  
the world**

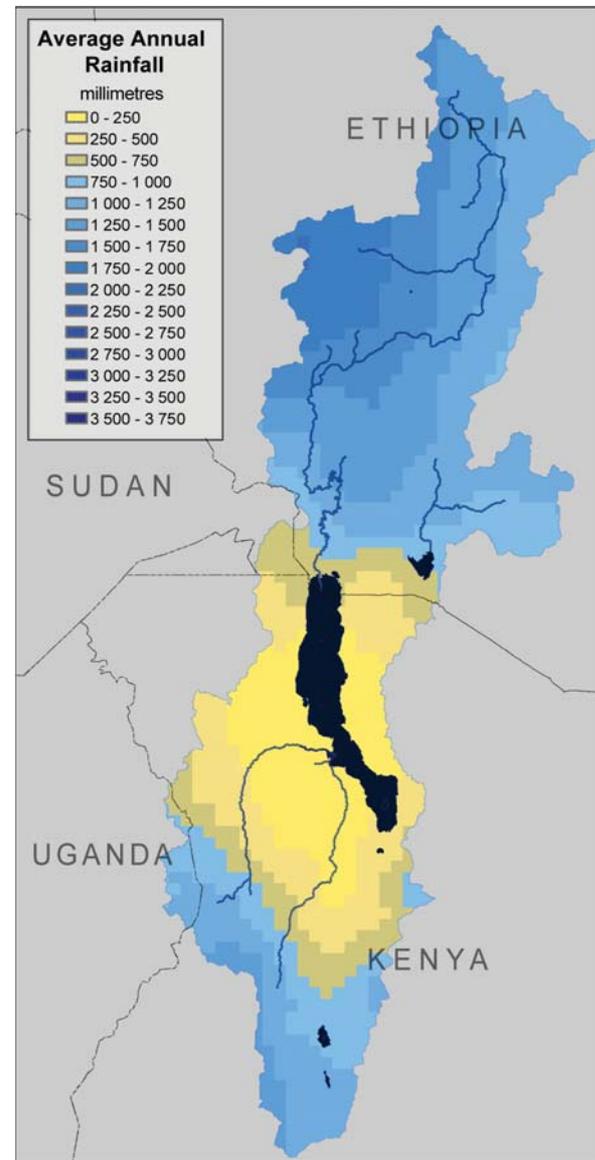
Just less than half of the basin lies in Kenya, where the lake itself is located. The Turkwel and Kerio Rivers flow into the lake from the south, although their contribution to water levels is minimal. The lake receives nearly all of its inflow from the Omo-Gibe River, which drains part of Ethiopia's highlands. Lake Turkana itself is the largest closed-basin lake in the East African Rift (Haack 1996) and the largest desert lake in the world (Angelei 2009). It has remained relatively isolated since it is in Kenya's arid north where the average temperature is 30° C and average annual precipitation is less than 200 mm (Nyamweru 1989). Water levels in Lake Turkana varied within a 20 m range between 1885 and 2008 (ILEC n.d., Legos 2009) and there is evidence that the 20th century's fluctuations were smaller than those before 1900 (Nicholson 2001).



**Figure 2.5.2 Lake Turkana Basin population density**

**Precipitation**

Averaged across the entire Lake Turkana basin, mean annual precipitation is well over 900 mm (Figure

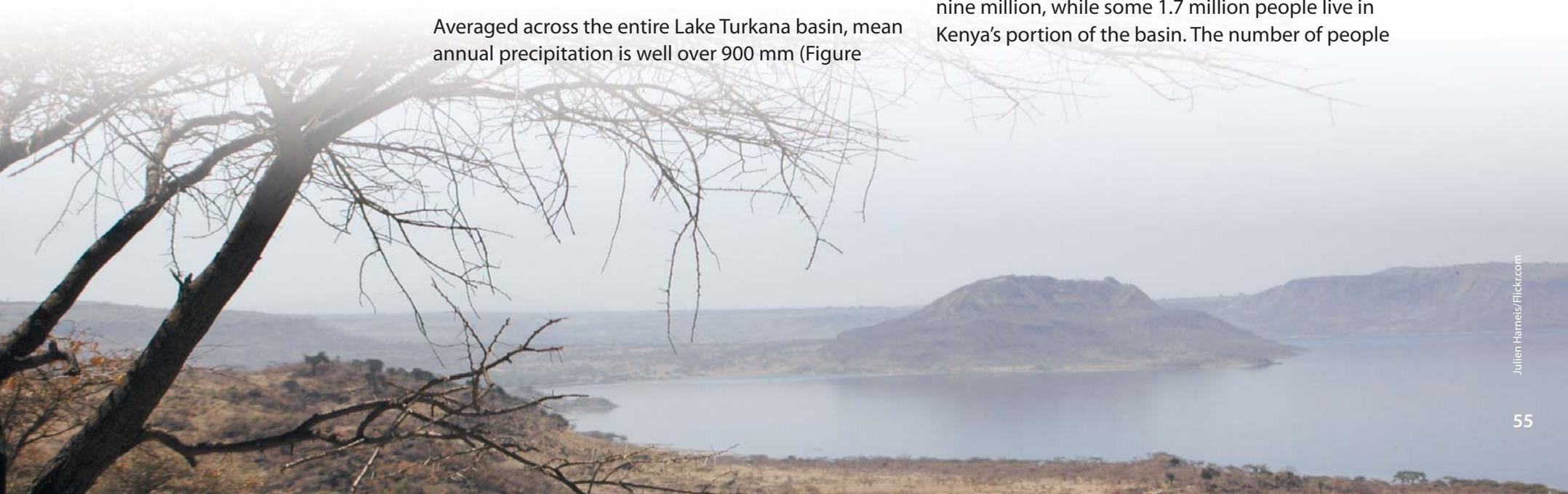


**Figure 2.5.1: Lake Turkana Basin average annual rainfall**

2.5.1). However, spatial variation is quite extreme with parts of Ethiopia approaching 2 000 mm of rain annually, while areas in northern Kenya receive less than 100 mm. In addition, high temperatures in northern Kenya and strong winds surrounding the lake quickly evaporate much of the erratic precipitation that does fall (ILEC n.d.). Lake Turkana receives 80 per cent of its inflow from the Omo River. The lower reaches of the Omo River as well as Lake Turkana and the communities that it supports rely on rainfall in the Ethiopian Highlands, which act as a "water tower." Recession-agriculture, flooding of grazing lands, fishing and recharge of shallow aquifers along the river's lower reaches all depend on the Omo River's volume and flow pattern.

**Population**

The total Ethiopian population in the basin is around nine million, while some 1.7 million people live in Kenya's portion of the basin. The number of people



living within 50 km of the lake, however, is estimated to be only around 215 000 (ORNL 2008). Population is concentrated in the upper fifth of the basin within Ethiopia and at the basin's southern-most limit in Kenya (SEDAC 2010) (Figure 2.5.2).

### Hydropower Facilities

A series of five hydropower facilities are planned along the Omo-Gibe River. The first dam, Gilgel-Gibe I, has been completed and filled. The second hydropower facility, Gilgel-Gibe II is fed by a 25 km tunnel running east from Gilgel-Gibe I Reservoir through a mountain to where the Omo River is 700 m lower. Gibe III has been under construction since 2006 and when completed will be the second-largest reservoir in Africa. Construction has not yet begun on two additional planned hydropower facilities, Gibe IV and Gibe V.

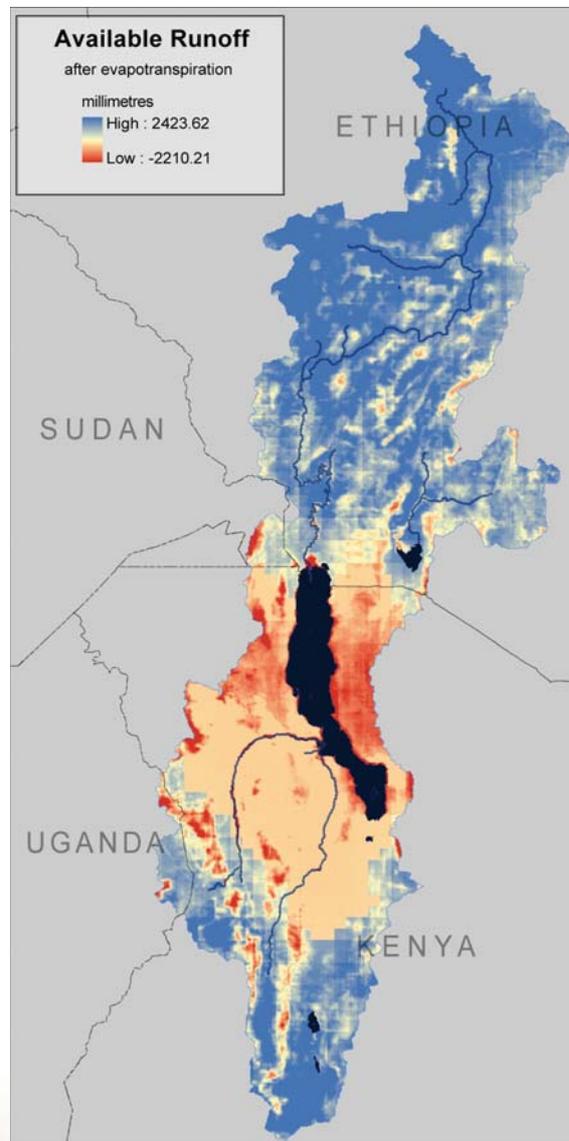


Figure 2.5.3: Lake Turkana Basin available runoff





**Figure 2.5.4:** The Gibe III dam was roughly one-third of the way to completion when this March 2009 image was acquired. It is expected to be finished around the end of 2013

### **Public discussion of the potential impact of Gibe III**

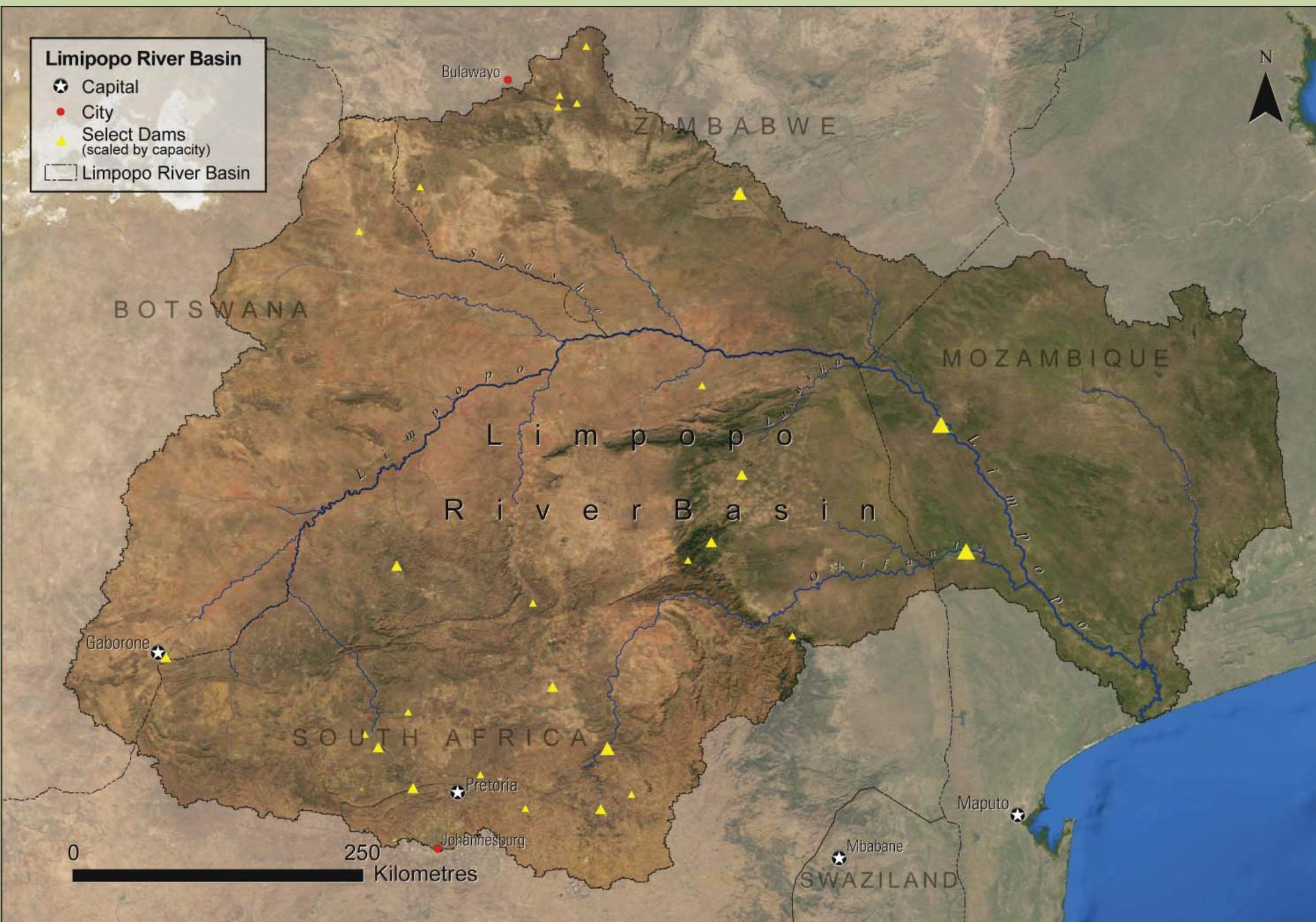
Proponents of the project, including the Ethiopia Electric Power Corporation (EPCo) and to some degree funding organizations such as the African Development Bank have defended the project and its importance for development in Ethiopia. Several opponents have raised concerns about the dam's impact on the environment generally and on downstream communities in particular. These critics say that the Environmental and Social Impact Assessments (ESIA) produced to justify the project were inadequate and missed several key concerns (IR 2009). They cite several likely impacts including reduced inflow to Lake Turkana, risk of earthquakes

and changes in the flow pattern that would prevent traditional recession agriculture and destroy riverine forests (ARWG 2009). The project's advocates defend the ESIA studies and point out the importance of electricity for development in Ethiopia. They assert that managing the flooding patterns will allow recession agriculture to continue and flooding will maintain many natural ecosystem functions (EPCo 2009). Preliminary results from a study of the basin's water balance has found that the planned Gibe III Dam project is not likely to have a significant impact on lake levels once the initial filling phase is complete. This assumes that hydropower generation remains the principal purpose (as is currently planned), with minimal water diversion for irrigation.

# Limpopo River Basin



The Limpopo River's largely semi-arid catchment receives most of its rains in a short, intense rainy season during the austral summer (December – February). The rains vary considerably within and between seasons making the basin susceptible to severe drought and flood events.



*The streamflow of the Limpopo is variable making irrigation unreliable*

The Limpopo River's flow is variable, often making irrigation directly from streamflow (without any form of impoundment) unreliable (CGIAR 2003). Because the basin has a large rural population, many of whom practice rain-fed subsistence agriculture, this variability can be disastrous (Reasons and others 2005). Many areas also have very high sediment loads, which discourages the construction of dams and irrigation schemes that would quickly fill with silt (CGIAR 2003).

**Precipitation**

The mean annual precipitation across most of the basin's northwestern half is below 500 mm/yr. The mean annual rainfall in Botswana's fifth of the basin is only 422 mm, while in Zimbabwe rainfall is just slightly higher at 469 mm. While parts of the basin's southeastern half also have somewhat limited rainfall, South Africa's mean annual precipitation is nearly 600 mm and Mozambique's is 729 mm, generally ample rain on an annual basis (Figure 2.6.1). The headwaters of the Limpopo's most significant tributaries, the Olifants and Crocodile Rivers, are in South Africa along the basin's southern edge and generally receive annual rains of 700 mm or more.

Rainwater runoff in most of the basin is lost to high rates of evapotranspiration and make little contribution to the river's water budget. Botswana receives almost 15 per cent of the basin's rainfall, but because of the arid environment it is all lost to evaporation and transpiration (Figure 2.6.2). Mozambique receives over one-quarter of the basin's precipitation but also has a negative impact on the water budget because of losses to evapotranspiration. Some of Mozambique's highest rates of water loss are through transpiration occurring in the wetlands along the river's course through Mozambique. By far the largest contribution to the river's flow comes from the Crocodile and Olifants catchments in the higher-rainfall areas to the northeast and northwest of Pretoria.

**Population**

Almost 80 per cent of the basin's over 15 million people live in the South African portion of the catchment, which includes Pretoria and much of Gauteng Province. Botswana, Mozambique and Zimbabwe each have roughly one million people living within the basin. Overall, the basin's population is around 60 per cent rural (CGIAR 2003). Growth rates were slower from 2005 to 2010 than in the previous decade for all of the countries sharing the basin (World Development Indicators 2010).

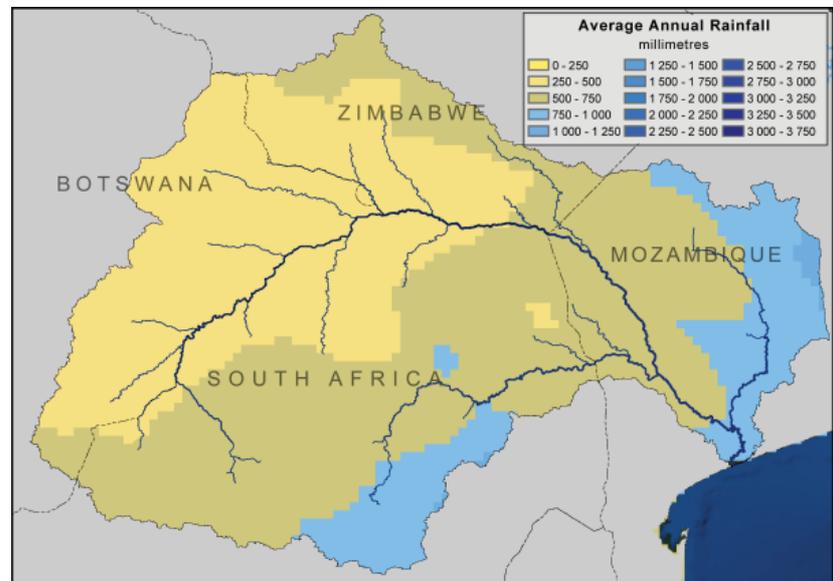


Figure 2.6.1 Limpopo River Basin average annual rainfall

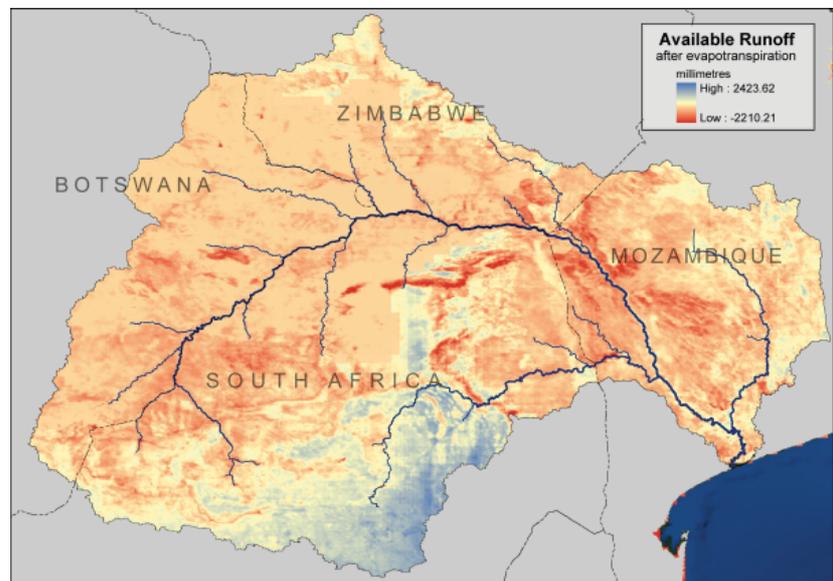


Figure 2.6.2 Limpopo River Basin modeled available runoff

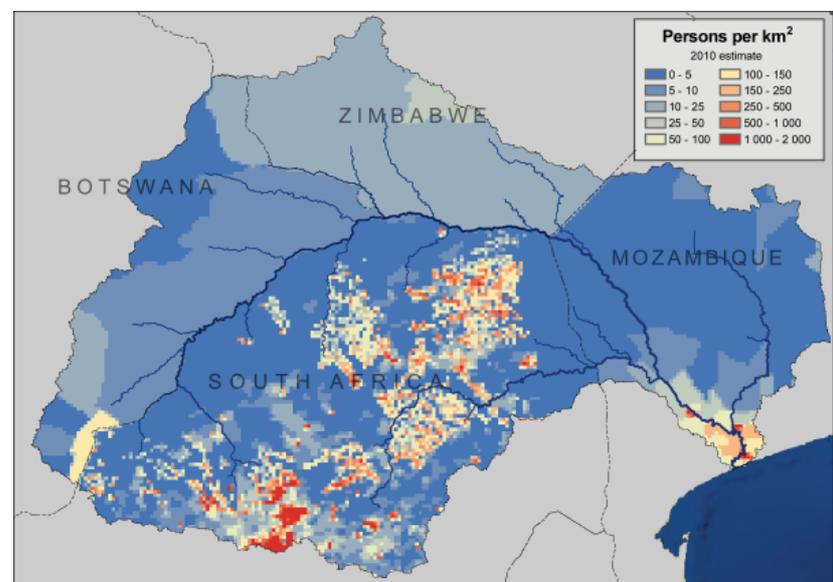
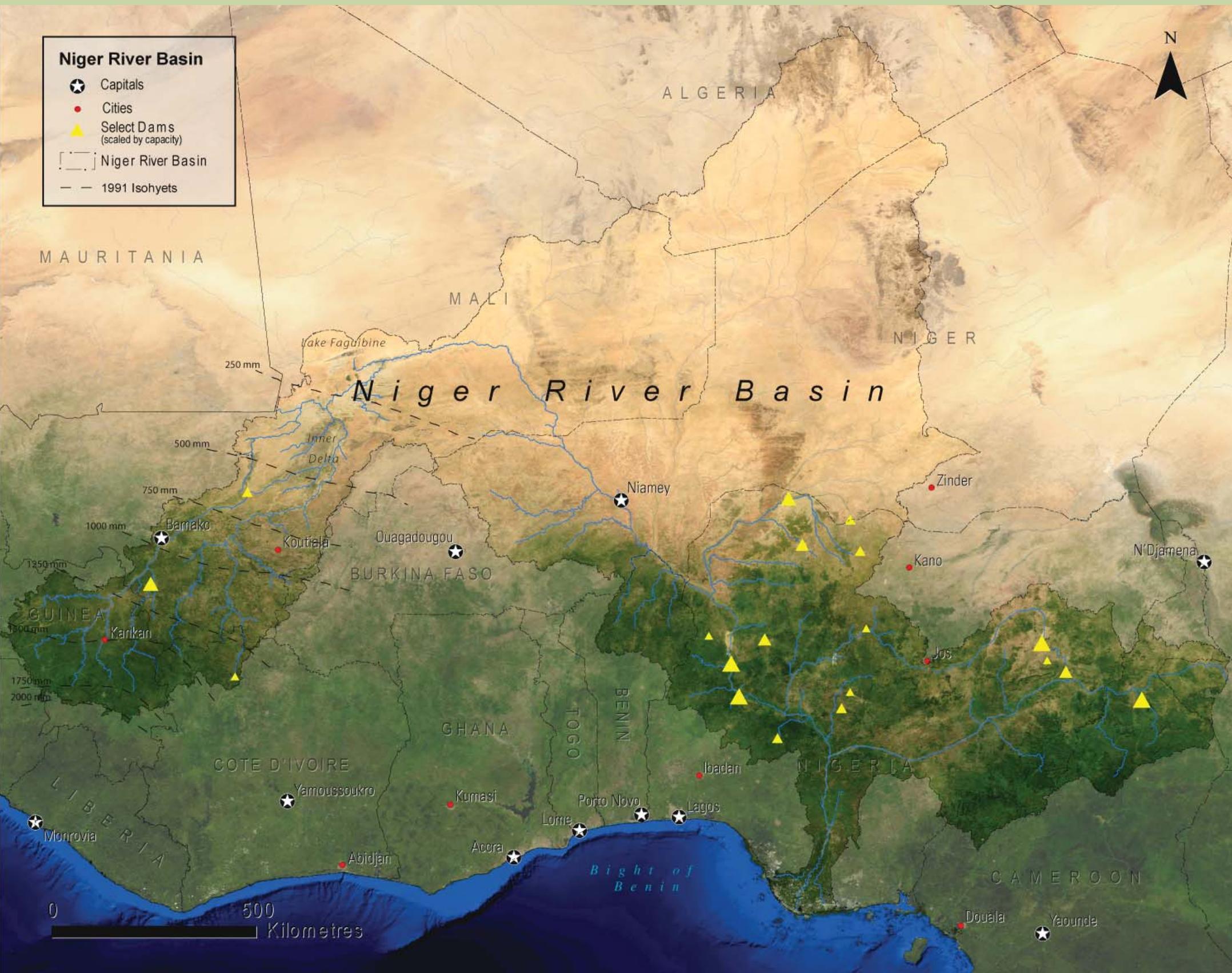


Figure 2.6.3 Limpopo River Basin population density

# Niger River Basin



The Niger River begins in the Fouta Djallon highlands in eastern Guinea and in the extreme north-western corner of Côte d'Ivoire. At 1 635 mm/yr in Guinea and 1 466 mm/yr in Côte d'Ivoire, the mean annual precipitation is the heaviest in the basin (FAO 1997).



## The Niger River sustains an island of vegetation and life in the harsh Sahel

As it flows northeast, the Niger River passes through the Inner Niger Delta in Mali where it sustains an island of vegetation and life in the harsh Sahel with its life giving water and seasonal flooding. Flowing further northward, it then passes through the southern edges of the Sahara Desert. Roughly 100 km northwest of Gao, Mali, the river turns to the south, toward Niger, Nigeria and eventually the Gulf of Guinea. The river has collected the flow of ten tributaries before it reaches Nigeria but arrives there with less water than when it left Guinea almost 2 000 km upstream (FAO 1997). Through Nigeria, rainfall increases from north-to-south as the river approaches the Niger Delta where it empties into the Gulf of Guinea.

### Population

The Niger Basin's total population is approximately 100 million, with a growth rate of around three per cent. Of this population, 67 million people live in Nigeria, just less than eight million in Mali and just over eight million in Niger (Anderson and others 2005) (Figure 2.7.1). There has been a rapid rate in urbanization throughout most of West Africa since the 1950s (AFD n.d.). Several of the resulting urban agglomerations fall within the Niger Basin, some of them located on the banks of the river, such as Niamey and Bamako. Access to improved water sources is an issue throughout most of the basin and projected population growth for the next few decades will increase the need.

### Precipitation

Guinea makes up less than five per cent of the basin by area but it contributes nearly one-third of the basin's water balance and almost all of the flow in the river's upper and middle reaches. Mali makes up nearly a quarter of the basin but because of its high average temperature and mean annual rainfall of only around 400 mm, it uses more water than it contributes to the river, much of it through evapotranspiration from the Inner Niger Delta. Niger and Nigeria each account for roughly a quarter of the basin's area. Niger's part of the basin receives an average of less than 300 mm/yr of rain and provides little runoff to the river. Nigeria's average rainfall within the basin approaches 1 200 mm and increases to over 2 000 mm near the coast (Figure 2.7.2, Figure 2.7.3).

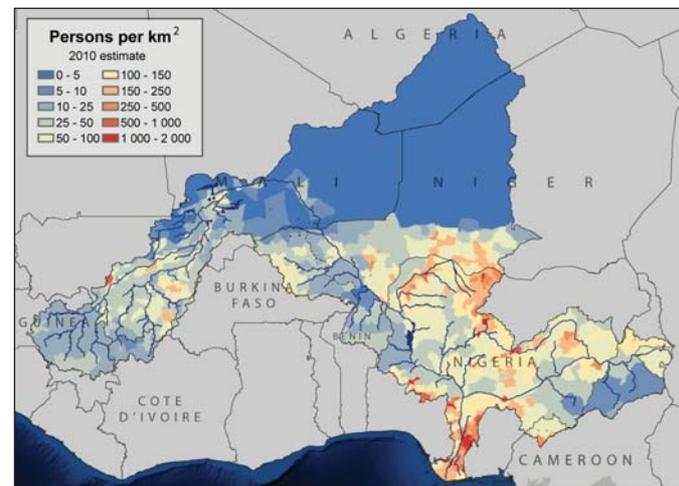


Figure 2.7.1 Niger Basin population density

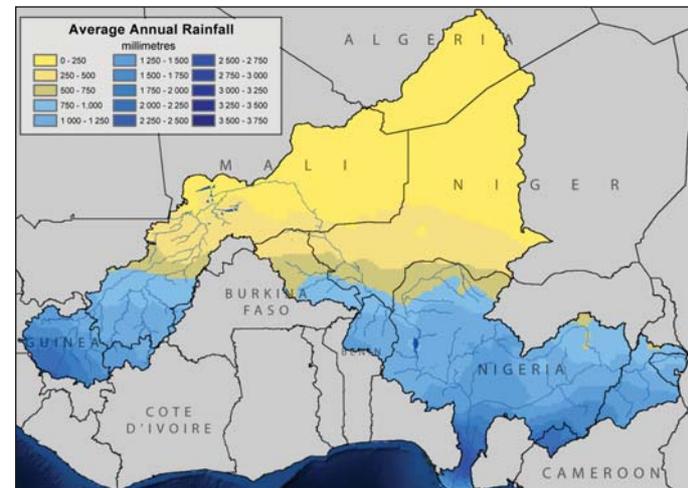


Figure 2.7.2 Niger Basin average annual rainfall

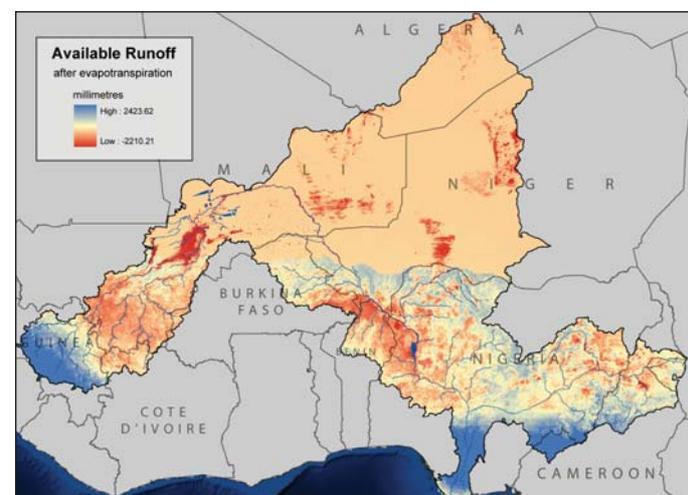


Figure 2.7.3 Niger Basin modeled available runoff



## Water Quality

For the most part, cities along the river have not developed collection and treatment plants for either industrial or domestic wastewater. In addition to urban pollution sources, agricultural runoff, particularly fertilizers, have been found at several sites (Anderson and others 2005). At the coastal delta, oil production has been the source of a host of environmental issues. Millions of barrels of oil have been spilled in the delta's oil producing region.

## Groundwater

High-quality aquifers can be found in the middle and lower reaches of the basin, including the lullemeden Aquifer System, and there are several very good quality aquifers in parts of Nigeria (Anderson and others 2005, Ludec and others 2001, OSS 2008). Studies of recharge rates and resource mapping have been carried out in some areas, but in many cases, they are lacking (Lutz and others 2009). Assessment and sustainable development of groundwater resources will require building systems for mapping and monitoring of resources as well as the institutional capacity to manage resources and enforce policy (BGR n.d.).



## Drought

A period of reduced rainfall across the Sahel began in the early 1970s and continued through the 1990s, with two periods of very severe drought in the early 1970s and early 1980s (L'Hôte and others 2002). Rainfall was more than 30 per cent below average for three consecutive years in the mid-1980s. The Niger River's mean annual discharge declined to less than one-third of its average flow at some gauging stations (Anderson and others 2005) decreasing at

almost twice the rate of the drop in rainfall during the 1970-2000 period (Descroix and others 2009, Andersen and others 2005, Lebel and others 2003). Paradoxically, as the rainfall decreased, changes in the land surface appear to have increased the rate of groundwater recharge, raising the water table in several areas of the Niger Basin. This is likely due to increased runoff caused by loss of surface vegetation and changes in land use. This rise in runoff is believed to have increased the number of ponds as well as their size and duration leading to increased infiltration (Descroix and others 2009).

The Sahelian droughts of the 1970s and 1980s spanned the Niger Basin (Nicholson 1983) causing famine, forcing dislocation of people and destroying livelihoods. Droughts are not uncommon in the Sahel and as already discussed on page 49, recent evidence suggests that much more severe droughts occurred as recently as 200 to 300 years ago with a pattern of similar droughts extending back at least a few thousand years (Shanahan and others 2009). It is becoming widely accepted that variations in sea-surface temperatures in the Atlantic and Indian Oceans are linked to these changes in rainfall patterns over Western Africa (Shanahan and others 2009, Zhang and Delworth 2006, Giannini and others 2003). It is not certain what impact global warming would have on future precipitation in the Niger Basin. Studies suggest possible scenarios of negative and positive impact but do not make predictions (Zhang and Delworth 2005, Giannini and others 2003).

## Dams and development projects

Many opportunities for investment and development in the Niger Basin are dependent upon developing and managing sustainable water projects, including hydropower, irrigation and flood management (Anderson and others 2005). Existing dams in the Niger Basin in Mali (Sélingué Dam) and Nigeria (Kanji, Jebba and Shiroro Dams) provide large-scale hydropower for their respective countries (Mbendi n.d.). Further dams are planned, including Tossaye Dam in Mali, (under construction) and Kandadji Dam in Niger (funded but not yet begun) (Figure 2.7.4). Irrigation is minimal in Guinea where successful rain-fed agriculture is predominant. In Mali, Sélingué Dam and two diversion dams—Sotuba and Markala—can provide water for 114 000 ha of irrigated crops



### Dams in the Upper Niger Basin

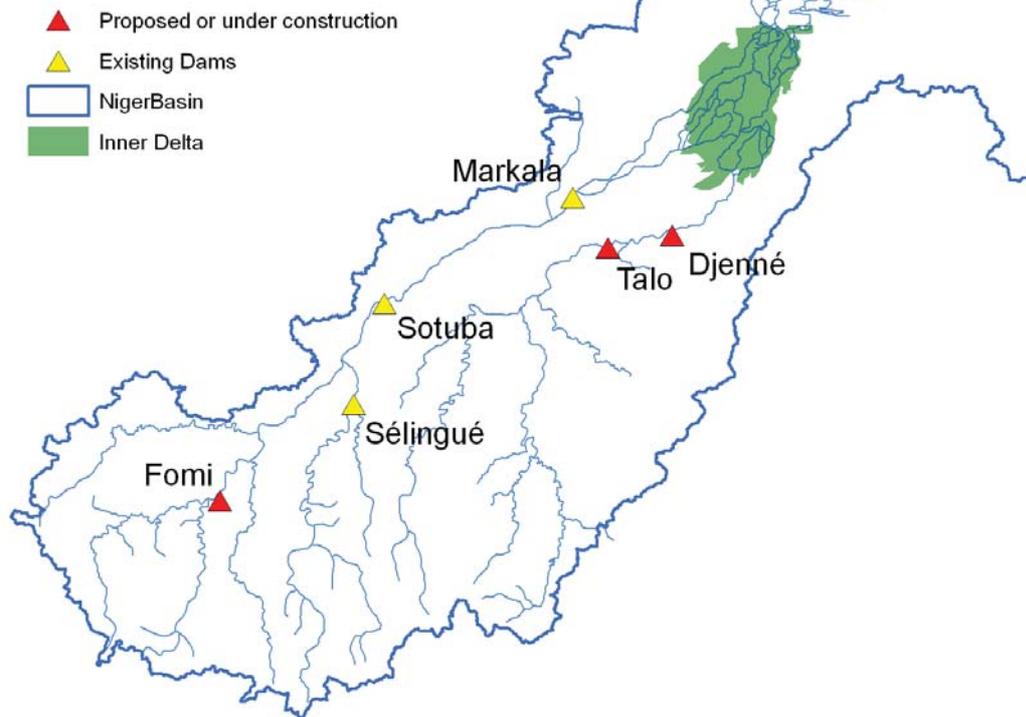


Figure 2.7.4: Dams in the Upper Niger Basin (Source: Zwarts and others 2005)

(FAO 1997). Only a fraction of the area equipped for irrigation in Mali is cropped (Zwart and Leclert 2009), and the ample availability of water in recent years has led to poor infrastructure maintenance (Vandersypen and others 2009). The construction of Tossaye Dam in Mali will bring 150 GWh/yr of hydropower capacity as well as irrigation to an additional 8 300 ha of land (Zwarts and others 2005) (Figure 2.7.4). In Niger, the Kandadji Dam, which has been under study for three decades is moving forward. It will increase the country's electricity supply by as much as 50 per cent, provide drinking water for Niamey and enable an irrigation scheme of 6 000 ha (AfDB 2008). Among the dam's negative impacts are the relocation of approximately 35 000 people living in the project area and the loss of around 7 000 ha of agricultural land that the reservoir would flood (UNEP 2007). The dam's potential effects, however, were identified early in the project's planning, allowing mitigation measures to be drawn up in subsequent phases of the planning process (UNEP 2007).

#### Fomi Dam

Other dams are under study for the Niger Basin including one in northeastern Guinea on the Niandan

River, an important tributary of the Niger River. The proposed Fomi Dam (Figure 2.7.4) would have 2.9 times the storage volume of Sélingué Dam, currently the largest dam above the Inner Niger Delta. Cost-benefit analysis of the existing Sélingué Dam found that significant costs, which included the loss of grazing and agricultural land and some change in downstream flow, were balanced by many positive benefits. Among them were a productive fishery, some irrigation, new avian habitat, and a stable electricity production. The same study found that the Fomi Dam was likely to have a greater negative impact downstream and that if Fomi was operated on a similar basis as Sélingué, its impact on flow would be proportional to its larger storage volume—or roughly three times as much impact on flow. It is estimated that this loss of flow would reduce rice production on the Inner Delta by 34 500 tonnes, 40 per cent of the current average production (Zwarts and others 2005). The analysis found that in addition to an unfavorable overall cost-benefit ratio, the benefits would disproportionately accrue to the upstream stakeholders while more of the costs would fall upon downstream ones (Zwarts 2005b).



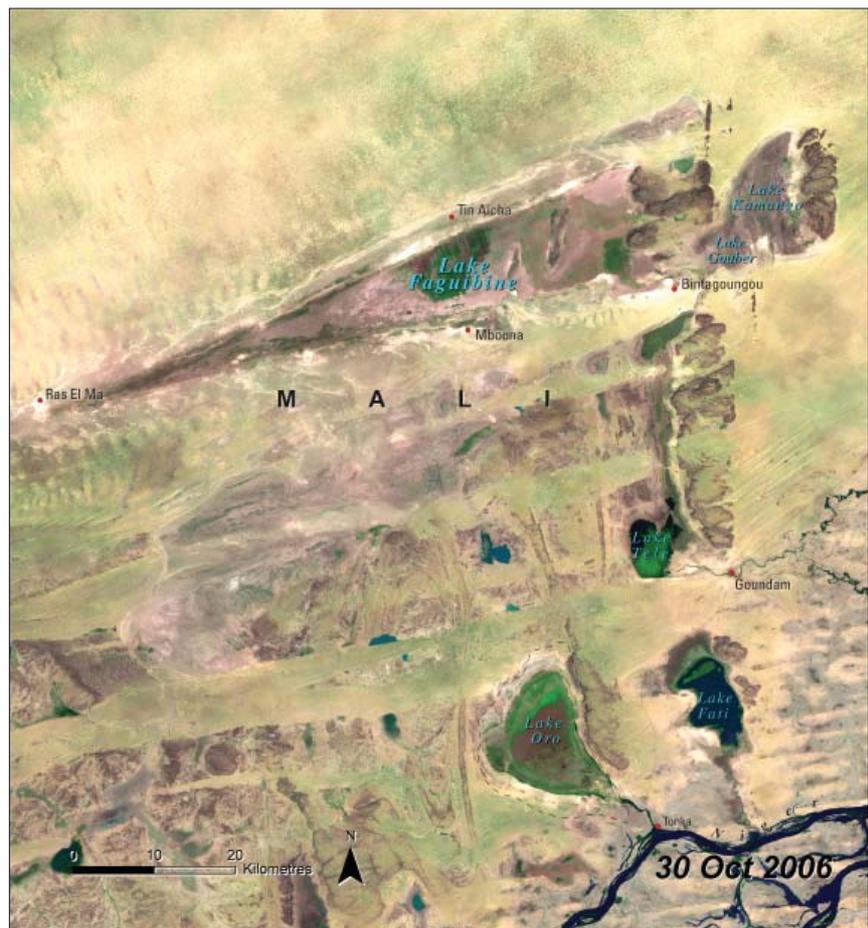
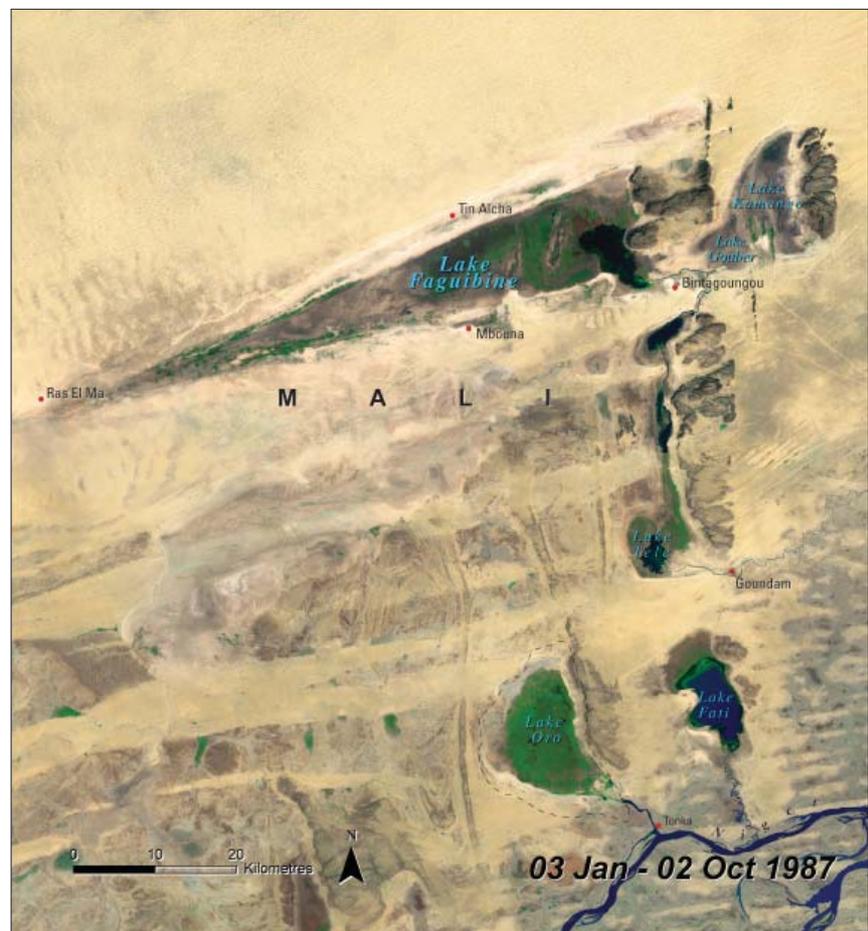


Figure 2.7.5 After drying up in the 1990s Lake Faguibine has not refilled significantly, however some pooling has occurred during wet years. Work is underway to clear debris from channels that feed the lake

### Lake Faguibine

Lake Faguibine is located in the Sahelian sub-desert zone to the west of Timbuktu in northern Mali. Annual precipitation in the Faguibine area is in the range of 250 mm/yr, with the rainy season beginning in mid-June and lasting three to four months. When Lake Faguibine is full, as it was in the 1970s satellite image (Figure 2.7.5), it is among the largest lakes in West Africa, covering approximately 590 km<sup>2</sup> (Duvail and Hamerlynck 2009). During the great droughts of the 1970s and 1980s, Faguibine began declining and in the 1990s it dried up completely. With the lake

all but gone, many local livelihoods also dried up including agriculture, fishing, and dry-season grazing (Duvail and Hamerlynck 2009).

The sparse rainfall is not enough to support rain-fed agriculture and cannot fill the lake without inflow from distant parts of the Niger Basin where the rainfall is heavier. The lake receives most of its water through two channels that carry water from the Niger River when its levels are high enough (CNEARC 2004). Despite some better rainfall years since the great droughts (Descroix and others 2009), Lake Faguibine has not significantly refilled, only forming



a small pond for a few years during the wet seasons since the 1990s. The 2010 wet season satellite image shows a pool of about 35 km<sup>2</sup> (six per cent of the 1974 surface area).

During the extended droughts of the 1970s and 1980s, the channels that carry water between the Niger and Lake Faguibine had become clogged with sand and vegetation (UNEP n.d., BBC

2009). The government of Mali has been working to clear the channels and recently received a commitment of US\$15 million from the United Nations Environment Programme to help support that work. A government official working with the project says that conditions are already improving with a dramatic increase in farming around the lake between 2006 and 2010 (BBC 2009).

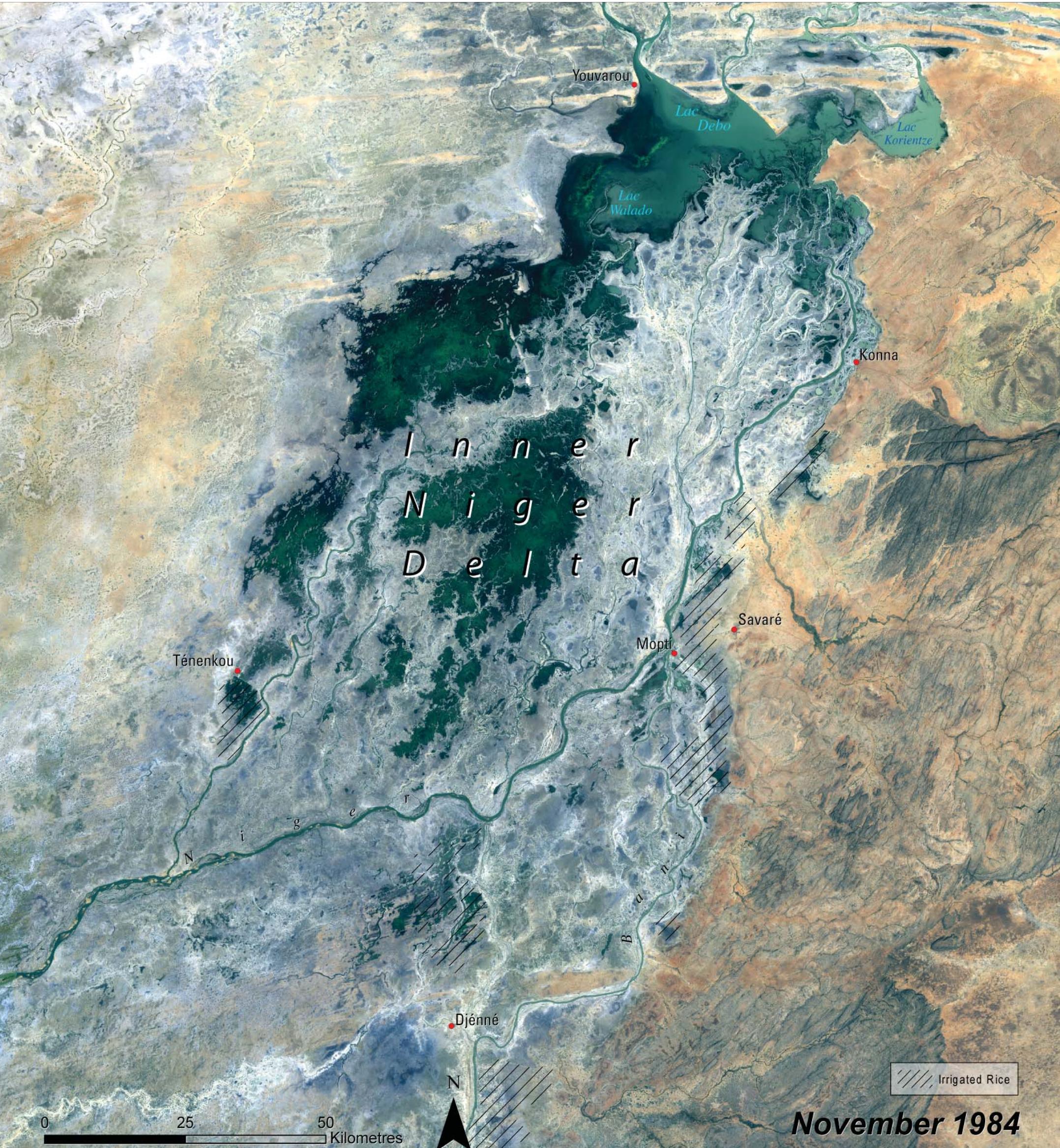
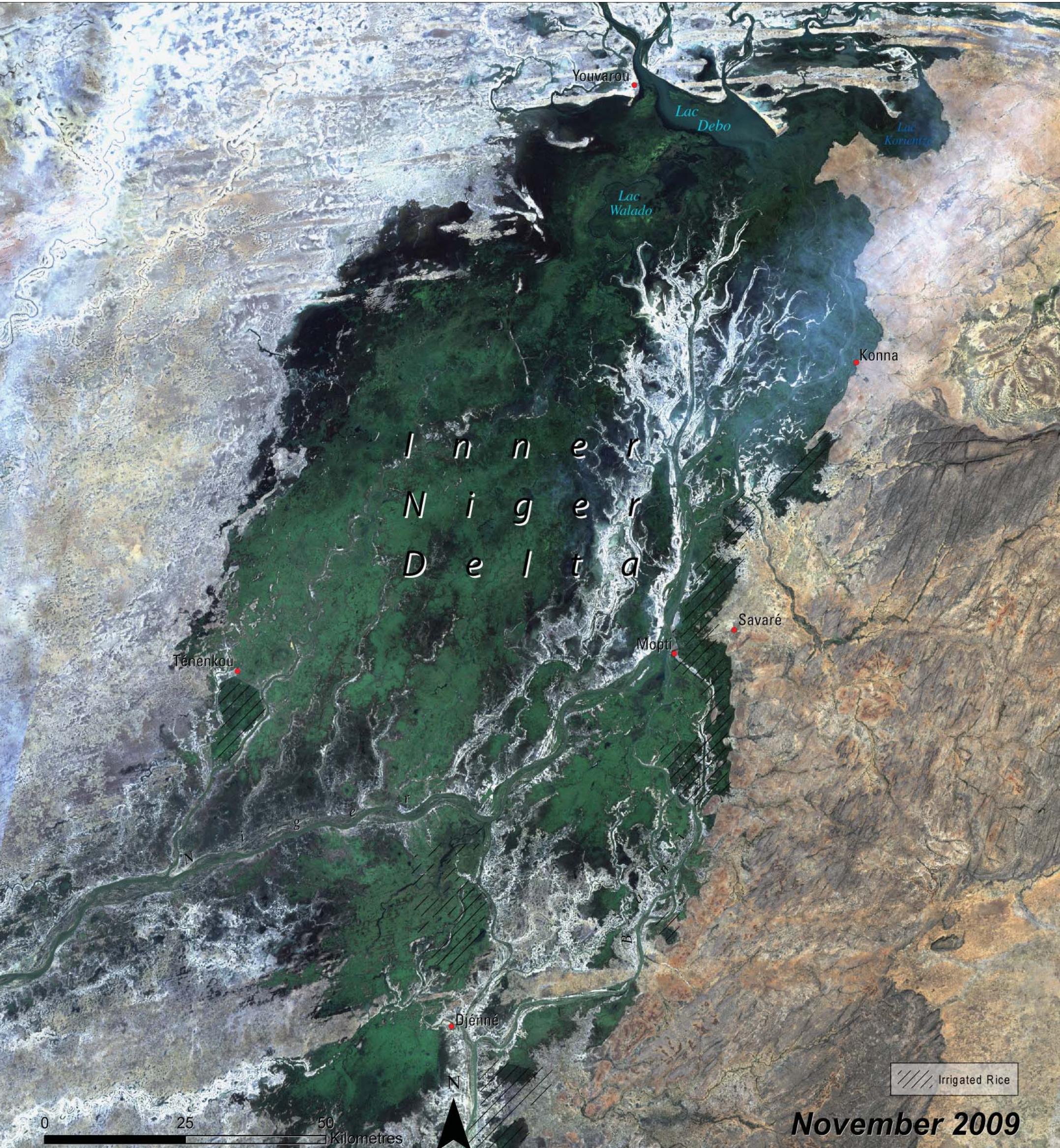


Figure 2.7.6: The Inland Niger Delta's annual floods were dramatically reduced during the great droughts of the 1970s and 1980s. In 2009, precipitation and flooding were more normal

### Inner Niger Delta

The Inner Niger Delta lies roughly 400 km northeast of Bamako, Mali where the Niger River divides into innumerable channels and is met by the Bani River. It is the largest wetland in Western Africa

(Ramsar 2004) spreading out along a very flat 200-km reach of the Niger River as it passes through the Sahel on its way north to the southern edges of the Sahara Desert. The Inner Delta is crucial to Mali's economy, its people and its natural environment. The delta supports about one million people, and a variety of ecosystem goods



and services, including a productive fishery, pasture for sheep and cattle, land and water for agriculture and habitat for natural flora and fauna. These attributes have earned it the designation as a Wetland of International Importance by the Ramsar Convention (Ramsar 2010).

The delta's water budget is complex and includes a significant groundwater component, which causes prolonged dry periods

to extend beyond the resumption of more normal precipitation until groundwater levels have rebounded. In addition, as much as 48 per cent of the delta's water is lost to evaporation (Mahe 2009). Flooding of the delta is dependant on rainfall over the upper reaches of the Niger River in the Guinean Highlands and to a lesser extent in the Bani in northern Côte d'Ivoire while rainfall over the delta

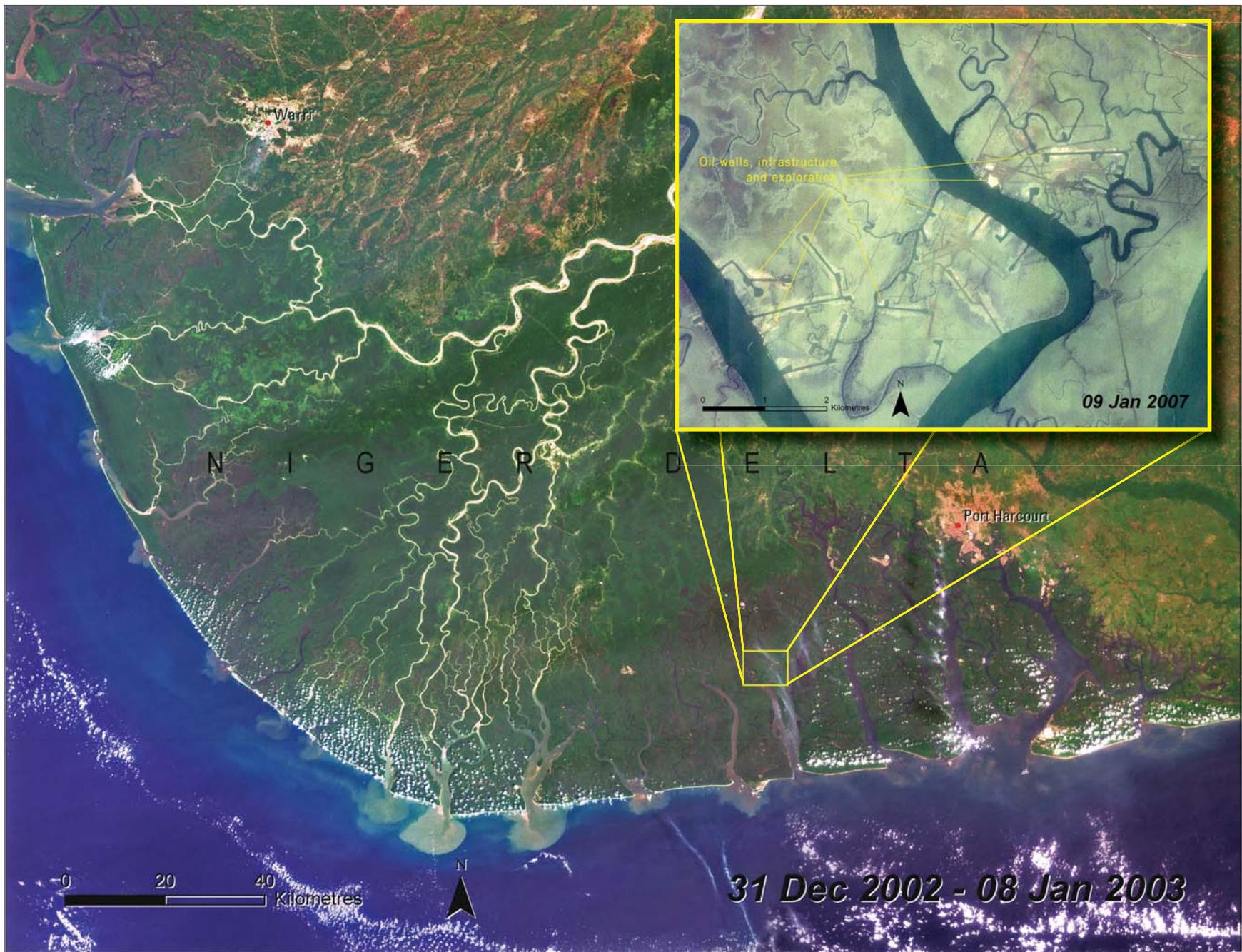


Figure 2.7.7: Oil wells and pipelines can be seen across much of the delta and spills here are a common occurrence

contributes only five to ten per cent of its water (Mahe 2009, Zwarts 2005). During the droughts of the 1970s and 1980s, flooding of the Inner Delta declined dramatically as can be seen in the pair of satellite images from the late-wet seasons of 1984 and 2009 (Figure 2.7.6, previous page). The 1984 image was taken during the prolonged drought while the 2009 image follows a more normal precipitation year.

### Niger Coastal Delta

The Niger Marine Delta (Figure 2.7.7) has formed over millions of years where the Niger River discharges into the Gulf of Guinea. The delta is home to approximately 31 million people (Amnesty International 2006). The delta is also widely recognized as an important natural





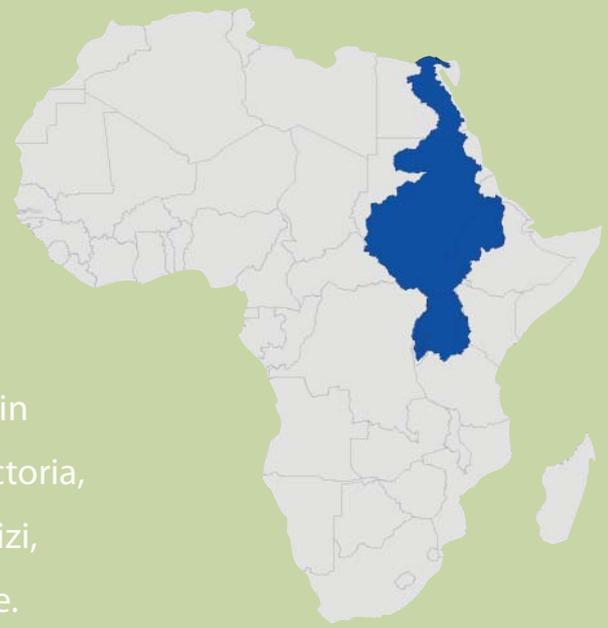
system supporting an array of plant and animal biodiversity—particularly in the delta’s 20 000 km<sup>2</sup> of mangrove forests (IUCN n.d.). The delta’s people, and the natural systems many of them rely on, co-exist with the vast majority of Nigeria’s 896 oil and gas wells (NNPC 2009) and the associated storage facilities, refineries and thousands of kilometres of pipelines (IUCN n.d.). Thousands of oil spills, totaling over three million barrels of oil (Yo-Essien 2005) and wastewater from oil production (Ajao and Anurigwo 2002, Adedeji and Ako 2009) are among the primary

causes of a serious decline in water quality in the delta region. Flaring of natural gas, which results in acid rain, is also a contributing factor.

Surface runoff from agricultural land and increased use of agricultural chemicals is also a significant problem (Adedeji and Ako 2009). Other key contributors are disposal of untreated sewage and effluents from domestic and industrial sources and poorly designed sanitary landfills (Ajao and Anurigwo 2002).



# Nile River Basin



The Nile begins its 6 800-km journey to the sea 1 600 m above sea level in northern Burundi. The Kagera is one of many rivers flowing into Lake Victoria, which include the Mara, Nzoia, Katonga, Kagera, Yala, Isanga, Sondu, Ruizi, Kibos, Simiyu and Sio; only one river flows out, however, the Victoria Nile.





**Nile River Basin**  
middle and lower

- ★ Capitals
- Cities
- ▲ Select Dams (scaled by capacity)
- ⎓ Nile Drainage Basin

0 500 Kilometres

The catchments of most of the inflowing rivers have dense rural populations where much of the land is used for subsistence agriculture. Outflow is controlled by the Nalubaale and Kiira Dams at Owens Falls, eight kilometres downstream from the Victoria shoreline. After leaving the lake, the river flows through Lake Kyoga, a shallow wetland complex that is an important fishery for Uganda (ILEC n.d.), then east to Lake Albert, which also collects inflow from the Semliki River. Flowing north across the Uganda-Sudan border, the river splits into two channels—the Bahr al-Jabal and the Bahr az-Zaraf. Flowing across broad flat plains, the rivers expand into a vast wetland, the Sudd Swamp. Covering around 8 000 km<sup>2</sup> during the dry season, the swamp seasonally overflows, flooding an area many times this size (Ahmad 2008). The vast surface area, heavy vegetation and high temperatures of the Sudd lead to the loss of roughly half the total White Nile's inflow through evaporation and transpiration (Sutcliffe and Petersen 2007). The remaining outflow moves north where it meets the Blue Nile, 500 km downstream at Khartoum.

The Blue Nile originates at Lake Tana, 1 800 m above sea level in the Ethiopian Highlands, where average annual rainfall is high and evaporation and transpiration are relatively low. It gathers more than 20 tributaries between Lake Tana and Khartoum, including the Rahad, Didessa, Dabus and Dinder Rivers (Sutcliffe and Petersen 2007). By the time it reaches the Roseires Dam 80 km into Sudan, it begins to lose more water to evaporation and transpiration than it receives in rainfall;

nevertheless, it has collected enough water to provide around 65 per cent of the Nile's flow at Khartoum where it joins the White Nile. Additional inflow from the Ethiopian Highlands comes through the Atbara River, which enters the Nile 300 km downstream.

From this point on, the combined effect of large and small irrigation schemes, increased temperatures and diminishing rainfall cause the river to lose more water than it receives. In northern Sudan, the Merowe Dam forms an artificial lake that will be 174-km long when full (Hildyard 2008). The Nile in Egypt begins with Lake Nasser, a reservoir created by the Aswan High Dam. One of the largest pumps in the world forces water from Lake Nasser into a channel that transports it onto the Western Desert where Egypt has begun a large irrigation and resettlement project (WaterTech n.d.).

As the Nile flows on from Aswan toward the Mediterranean Sea, it is lined with irrigation canals. Almost all of Egypt's population of 78 million people live along the river and depend heavily on its resources. By the time the river reaches the sea, much of its water has been diverted for irrigation. Along with the water, sediments that have not already been trapped behind the river's many dams are diverted as well. As a consequence, erosion at the delta's margins and subsidence or compaction of the delta's soil is outpacing new deposition, leading the delta to sink and erode (Bohannon 2010).

*Almost 78 million people in Egypt depend heavily upon the Nile*



Bruce Pengra/UNEP GRID Sioux Falls

## Population

The Nile Basin has three of the heaviest population concentrations in Africa; surrounding Lake Victoria in Kenya and Uganda; in the Ethiopian Highlands surrounding the Blue Nile; and along the banks of the Nile in Egypt. While Egypt only accounts for nine per cent of the basin's area, it holds almost one-third of its population. In contrast, almost 64 per cent of the Nile Basin falls in Sudan but a little less than 36 million people, or about half as many as in Egypt, live there (CIESEN 2010). The 35 million Ugandans within the basin live on only 7.6 per cent of the basin's area. Kenya's 1.6 per cent of the basin has a still-higher population density, averaging about 320 people per km<sup>2</sup>. Ethiopia has about 35 million people within the Nile basin, but with 363 315 km<sup>2</sup> in area, population density is lower at about 97 people per km<sup>2</sup>.

In total, almost 224 million people live within the basin—almost one-quarter of Africa's population. Four of the basin's 11 countries have population growth rates in the top ten globally; all but two are above the

mean growth rate for Africa and all are well above the global average (UNESA 2008). While growth rates within the basin are expected to decline, most projections are still well above two per cent per year over the next two decades.

Urban populations are growing rapidly throughout the basin. Burundi is the most rural of any of the basin countries with only 11 per cent of its people in cities, although its urban areas are growing at 6.8 per cent/yr (UNESA 2007). Sudan and Egypt are the most urban of the Nile Basin countries with 45.2 per cent and 42.8 per cent of their respective populations living in cities. By 2030, it is expected that in half of the basin's countries, the majority of their people will live in cities.

The dense population surrounding Lake Victoria has grown faster than Africa's overall population during every decade since 1960. One estimate of the population in 2010 shows over 35 million people living within 100 km of the lake and twice that many people living within Lake Victoria's watershed, which extends across Rwanda, Burundi, Tanzania, Uganda and Kenya (CIESEN 2010)(Figure 2.8.2). The lake's resources are crucial to the livelihoods of many of these people and significant to all of them. The expanding population has led to increased deforestation, land conversion, agriculture, livestock numbers, industrialization, waste disposal and fishing pressure (Lehman 2009). This dense population and consequent changes in the surrounding environment have had a profound impact on the lake and the ecosystems of which it is a part.

With 11 countries and 224 million people sharing the Nile's waters across very different climatic regions, water management, particularly transboundary water management is very complex. In an area characterized by water scarcity and poverty, rapid population growth will likely compound the difficulty for the foreseeable future.

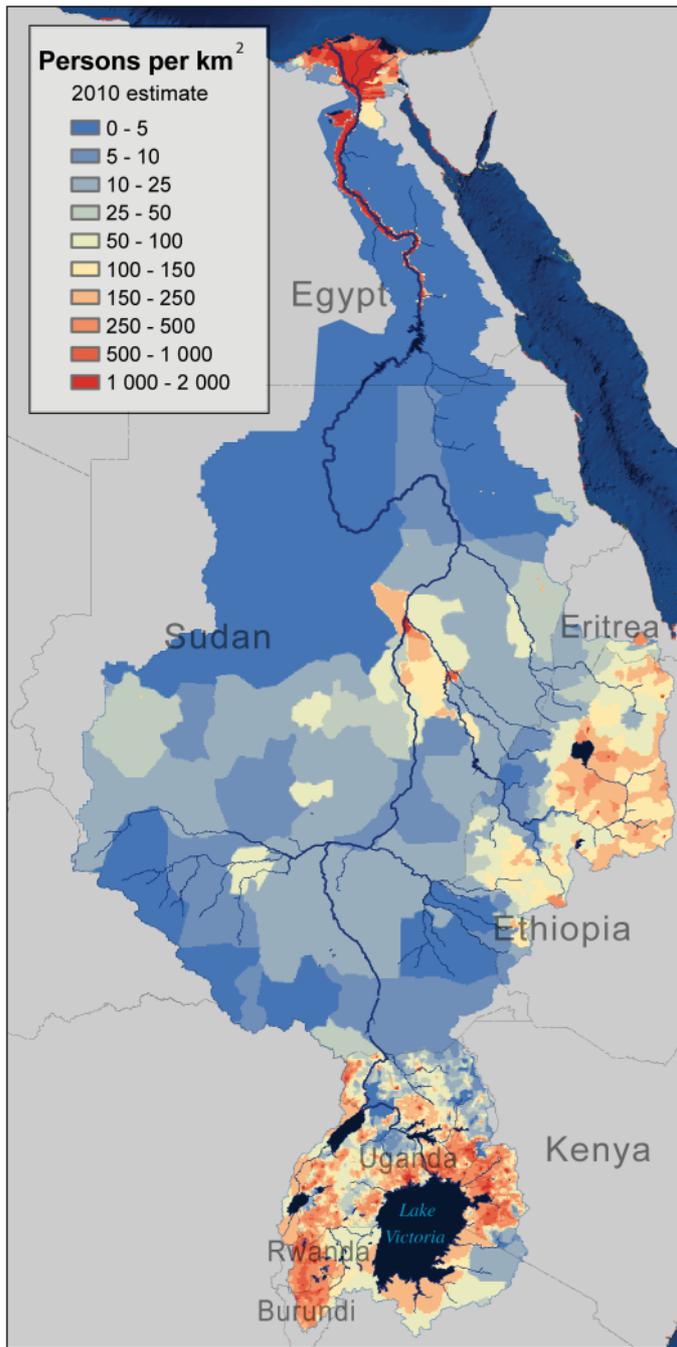
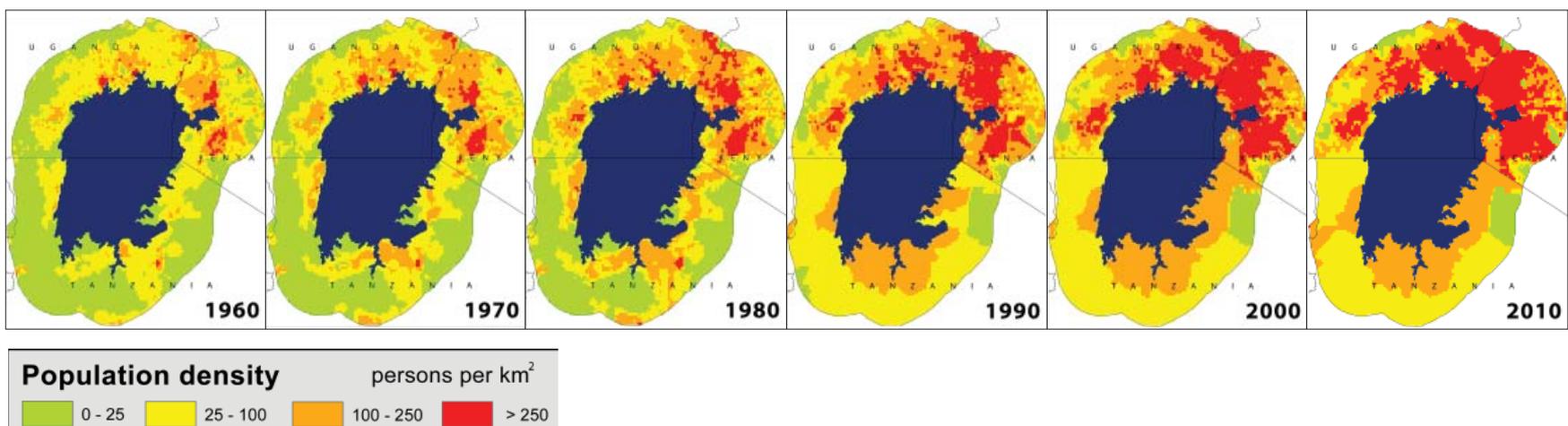


Figure 2.8.1 Nile Basin population density

Figure 2.8.2: The dense rural population surrounding Lake Victoria has grown dramatically since 1960 (SEDAC 2010)



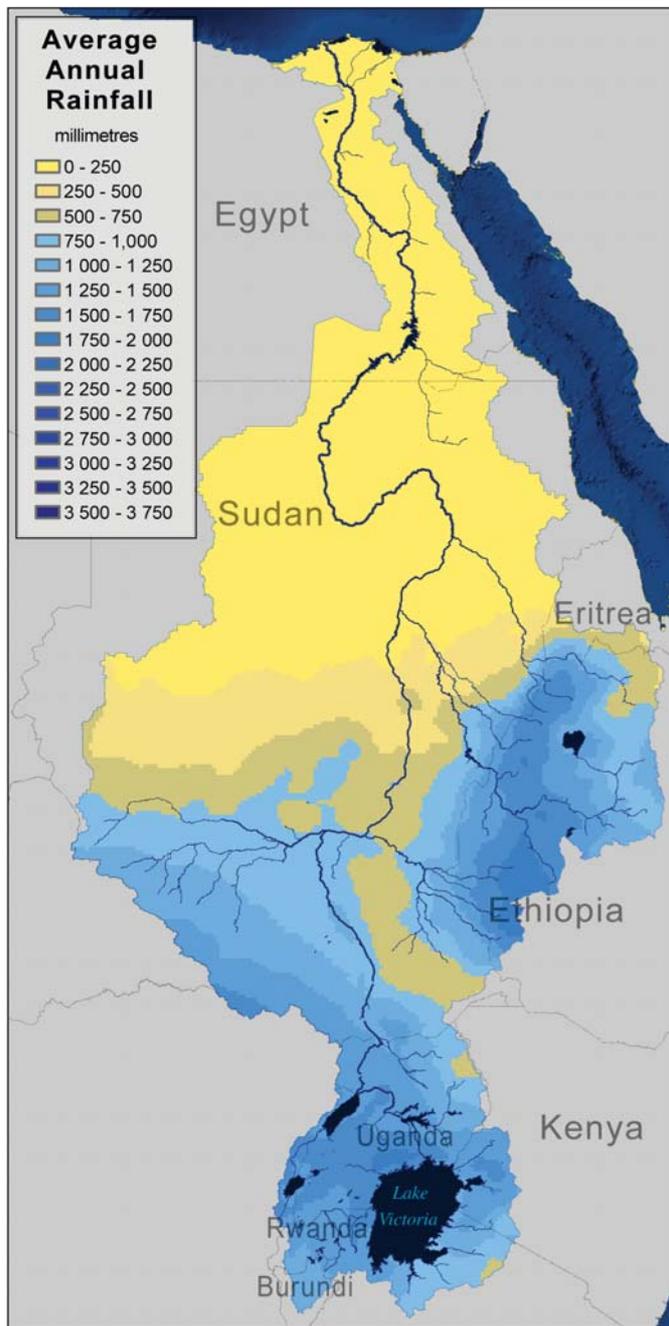


Figure 2.8.3 Nile Basin average annual precipitation

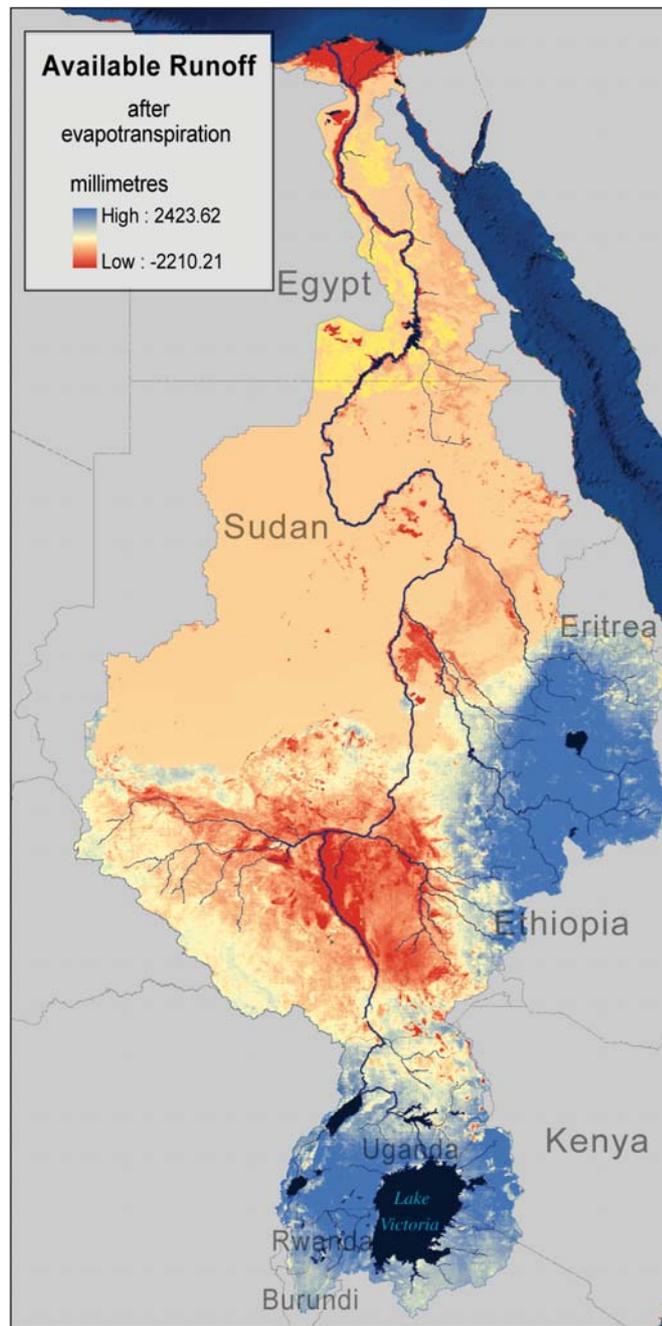


Figure 2.8.4 Nile Basin modeled available runoff

### Precipitation and Water Budget

Great extremes in average annual precipitation and evapotranspiration divide the basin's countries into net users of water and net contributors to the water budget, with extremes at both ends of the continuum. Egypt receives an average of around ten mm of rain annually within its part of the basin. In addition, the heat of the desert and the consequence of water transpiration over the vast areas of irrigation make Egypt a net user of water. It relies entirely on water from upstream wetter countries to survive. Sudan is also a net user of water. Although it

receives 46 per cent of the basin's total rainfall, high temperatures, irrigation, and the Sudd Swamp create enormous water losses to evapotranspiration.

At the other extreme, Ethiopia receives only 22 per cent of the basin's total rainfall but lower temperatures and evapotranspiration in the highlands allow much of that water to run off. Thus, Ethiopia contributes well over half of the Nile River's total water budget. Uganda, Tanzania and Kenya also contribute significant runoff to the Nile, although much of this water is lost in the Sudd Swamp in southern Sudan before it reaches Khartoum.

## Dams, Irrigation and Water Agreements

While the amount of water in the Nile Basin may fluctuate due to climate change and climate variability, it can be safely assumed that water availability will not increase. Since the projected population growth in the basin will be above average, this limited resource must be divided among more and more people. This makes it even more crucial to manage water sustainably, both within and among the basin's countries. Development projects are underway in several of the basin's countries and are being considered in others. They include hydropower dams, irrigation projects, and other water-diversion projects (Figure 2.8.5). All of them have implications for resource use throughout the basin, irrespective of regional and national boundaries.

Regulation of Lake Victoria's outflow at Jinja, Uganda, has a clear effect on the lake's water levels (Kull 2006, Swenson and Wahr 2009, Kiwango and Wolanski 2008, Sutcliffe and Petersen 2007) and less direct impacts on many of the lake's other ecosystem functions (Kiwango and Wolanski 2008, Minakawa and others 2008). These effects are also experienced by Tanzania and Kenya, who share the lake with Uganda, and to a lesser extent by all of the downstream countries in the basin. Deliberations about construction of the Jonglei Canal in southern Sudan continues (Sudan Tribune 2009) in spite of concerns about serious environmental impacts (Howell and others 1988, Krishnamurthy 1980, Laki 1994) on a wetland that is listed as a Ramsar Wetland of International Importance (UN News Centre 2006). The water the canal would save from evaporation and transpiration, however, could be of immense value for agriculture to the downstream communities in Egypt and Sudan. In Egypt, large volumes of water are being diverted onto the desert to irrigate crops and create a new area of settlement and jobs for Egypt's growing population. The demands for water that this will create, however, have very important implications for water development in both upstream and downstream locations.

The literature often predicts that water scarcity will be a future source of conflict between countries that share it. If this is so, the Nile Basin would be a very likely trouble spot with its many riparian countries and unequal distribution of water resources. However, recent scrutiny of the history of disputes over water resources suggests that violent international conflict is rare. Rather, countries are more likely to cooperate in managing shared water resources (Barnaby 2009, Yoffe and others 2003). The formation of the Nile Basin Initiative in 1997 is just the latest of many attempts to work together to manage

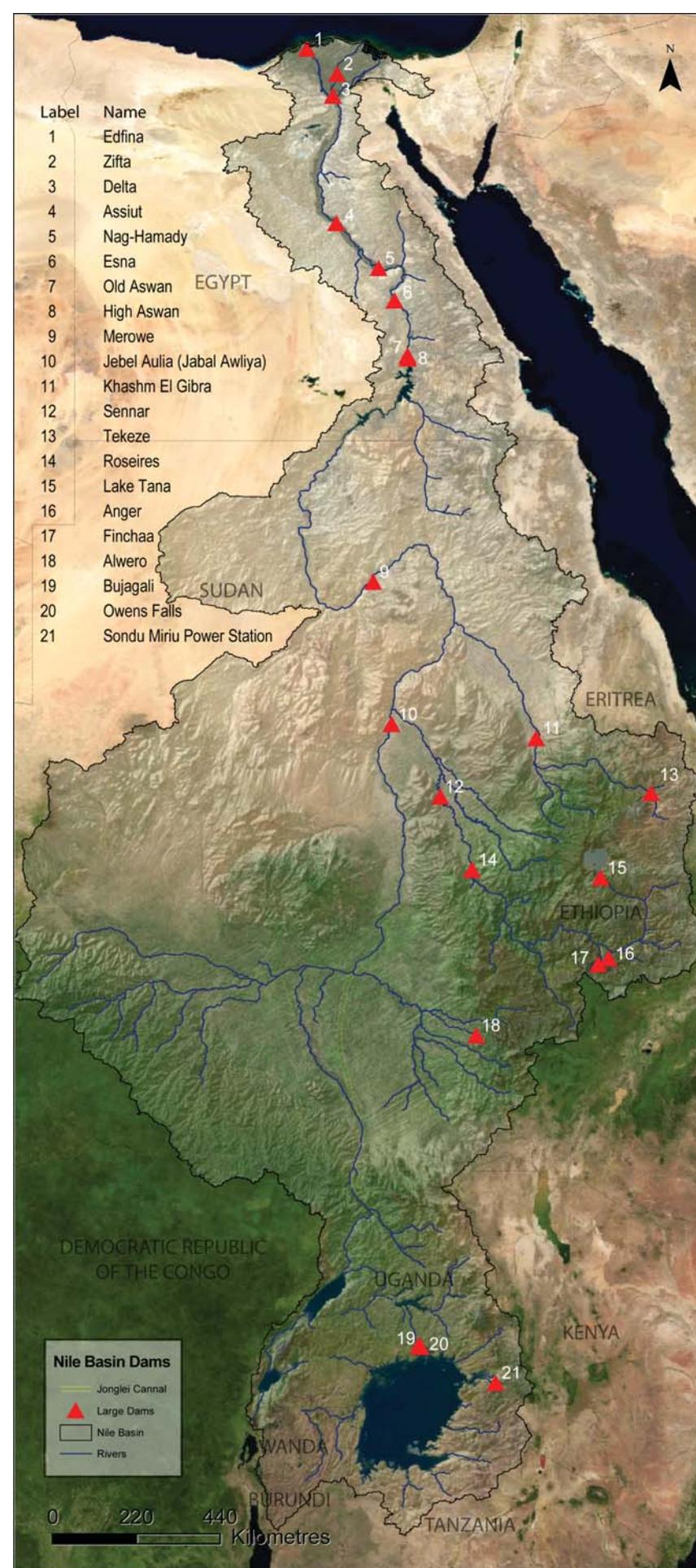


Figure 2.8.5 Dams and Water Projects

the Nile's resources across national boundaries; it remains a work in progress (Cascao 2009) as countries continue to review hydropower and irrigation project proposals (IR 2006).



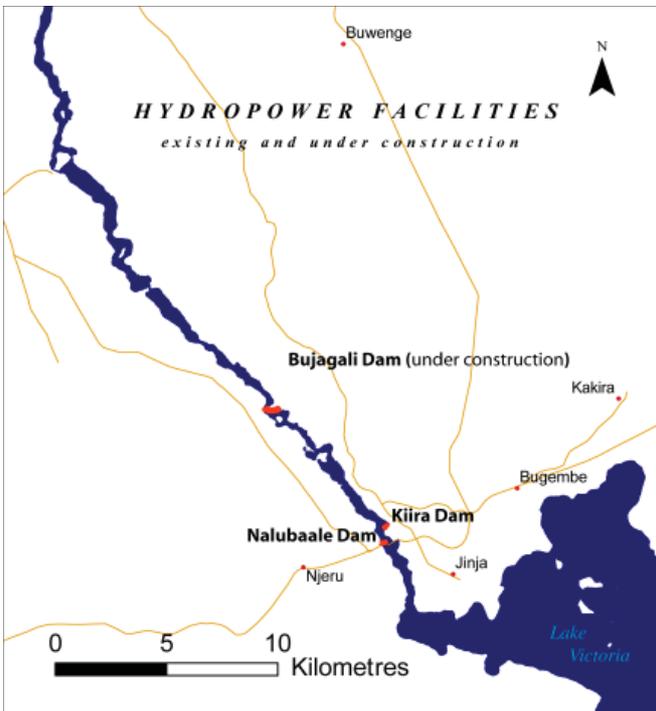


Figure 2.8.6: Hydropower facilities

### Lake Victoria, Owens Falls Dams, and Water Levels

The majority of the input to Lake Victoria's water budget derives from rainfall directly over the lake (82 per cent of inflow) and evaporation (76 per cent of outflow) (Kiwango and Wolanski 2008). The primary inflowing stream is the Kagera River, which enters at the lake's southwest corner. There are several smaller streams that enter along the lake's eastern and southern shores. The only out-flowing stream is the Victoria Nile at Jinja, Uganda. Since 1959, the Nalubaale Dam has controlled the outflow at Jinja (Kull 2006) (Figure 2.8.6).

Water levels in Lake Victoria declined by two metres (GRLM 2010) between the time the Kiira Dam was built at the same location in 1999 until the end of 2006, raising questions about the possible connection with water releases through the dams at Jinja (Kull 2006). Multiple studies have found that as much as half the decline in the lake's level during this time period was due to outflow at the Jinja Dams in excess of rates stipulated in an agreement with Egypt; these rates were designed to maintain the relationship between the outflow and lake levels that existed before the dams were built (Kull 2006, Swenson and Wahr 2009, Kiwango and Wolanski 2008, Sutcliffe and Petersen 2007). A



Figure 2.8.7: Location of the Nalubaale and Kiira dams

third dam, Bujagali Dam, is now under construction approximately ten kilometres downstream from the existing dams. Assumptions about future water levels are necessary in planning these dams and their current and future operation. Recent scientific investigations have found dramatic and sometimes rapid changes in the lake's level over the past two centuries (Sutcliffe and Peterson 2007, Nicholson and Yin 2000). The future viability of hydropower from the Victoria Nile is generally as uncertain and variable as the climate. The lake's water level may also affect other ecosystem services, such as fisheries, wetlands, invasive species as well as water quality (Kiwango and Wolanski 2008) and malarial mosquito habitat (Minakawa and others 2008).

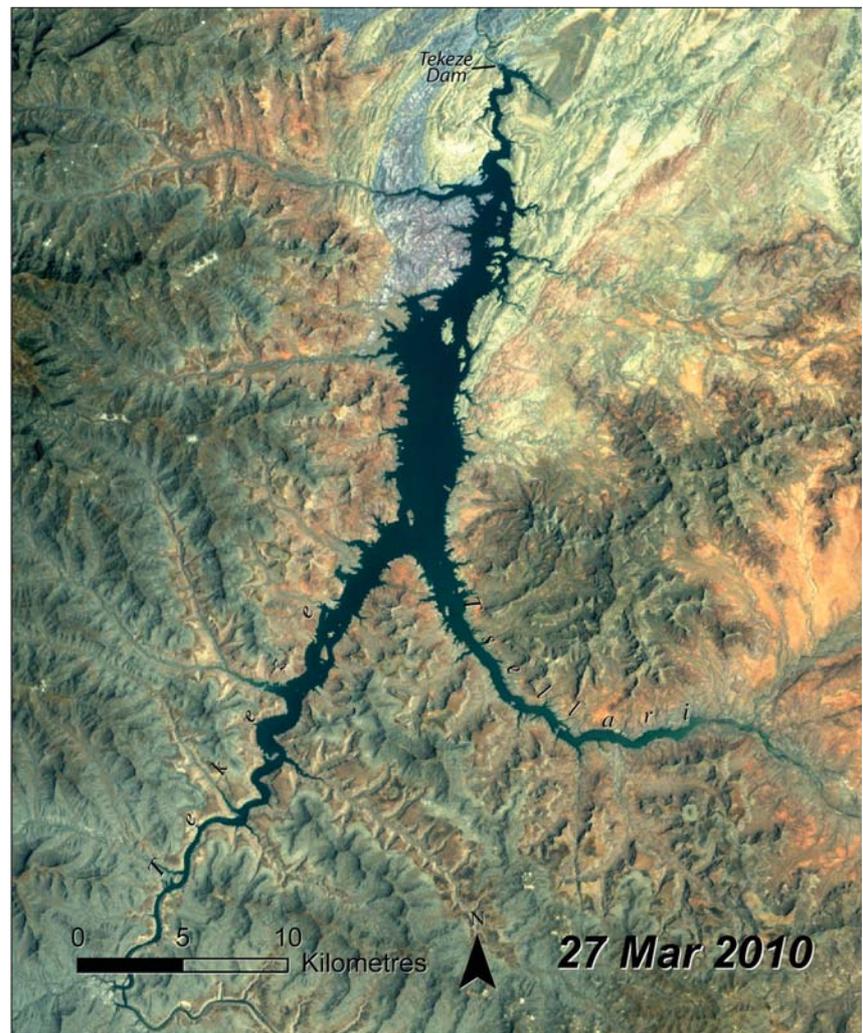
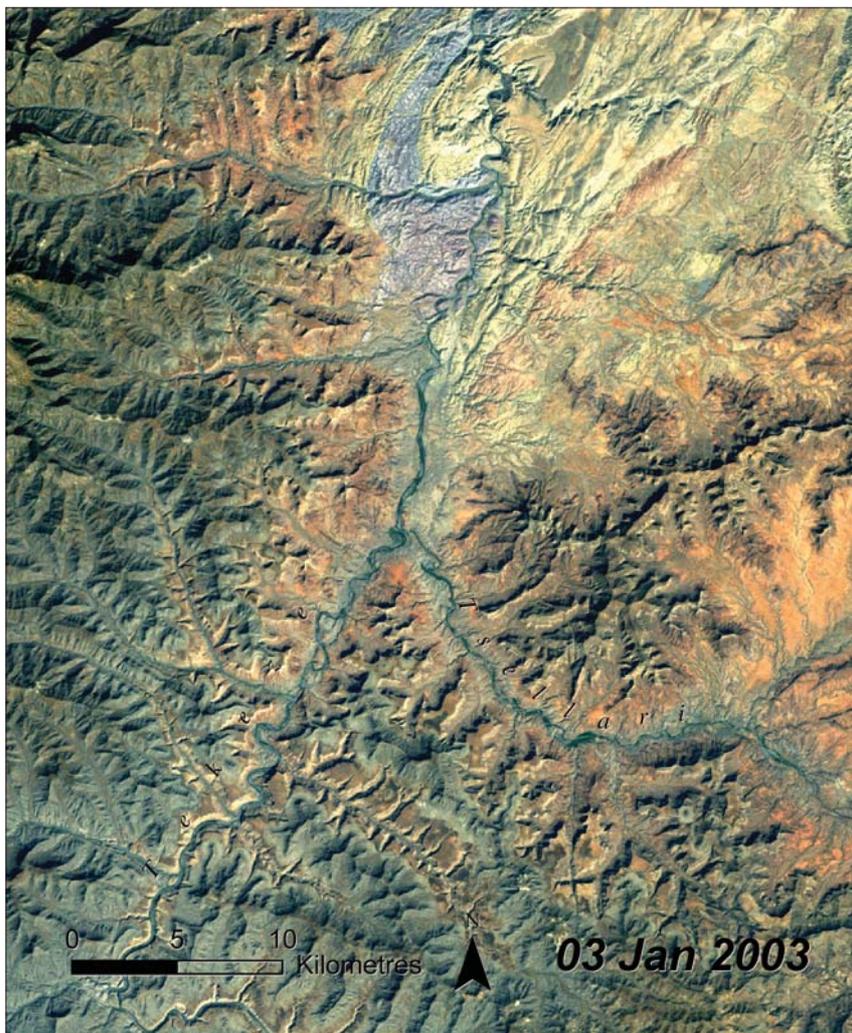


Figure 2.8.8: Tekezê Dam site, before and after the closing of the dam construction



Tekezé Dam in Northern Ethiopia

### Tekezé Dam

The Tekezé River in northern Ethiopia is a tributary of the Atabara River, which joins the main course of the Nile 300 km north of Khartoum. In early 2009, a Chinese contractor completed the Tekezé Dam, which rises 188 m from the river bed, at a final cost of around US\$365 million. The dam is intended primarily for hydropower generation and is expected to produce 300 MW when fully operational. Undertaken

without the endorsement of the nascent Nile Basin Initiative, the Ethiopian Electric Power Corporation (EEPCo) partnered with the Chinese National Water Resources and Hydropower Engineering Corporation for the project. As with many other large hydropower dams, concerns have been raised about the dam's environmental impacts. In 2008, a large landslide necessitated the addition of massive retaining walls to keep the slopes from eroding, adding an additional US\$42 million to the project's cost.

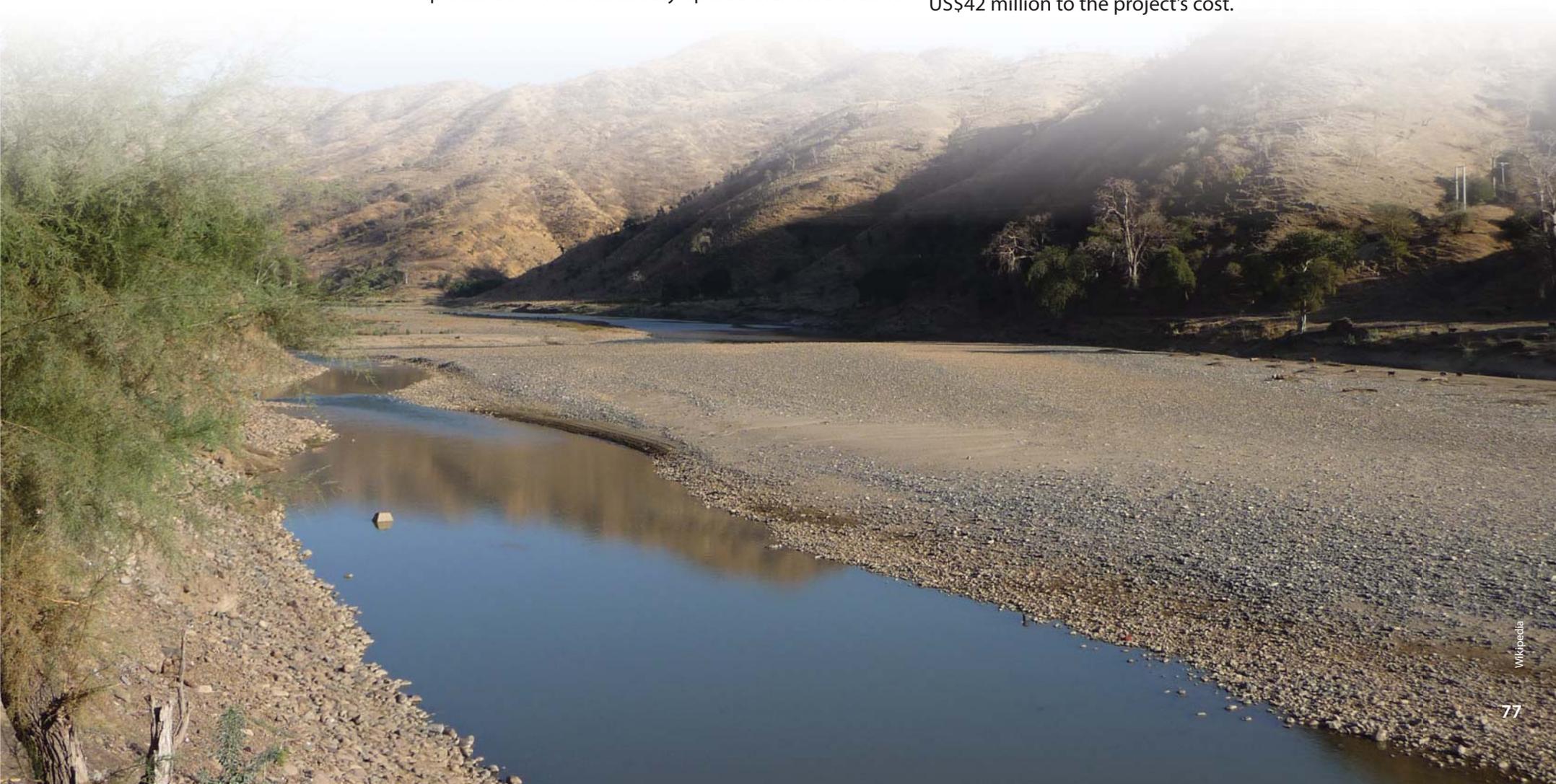




Figure 2.8.9: Merowe Dam on the Nile's fourth cataract was completed in March 2009

#### Merowe Dam

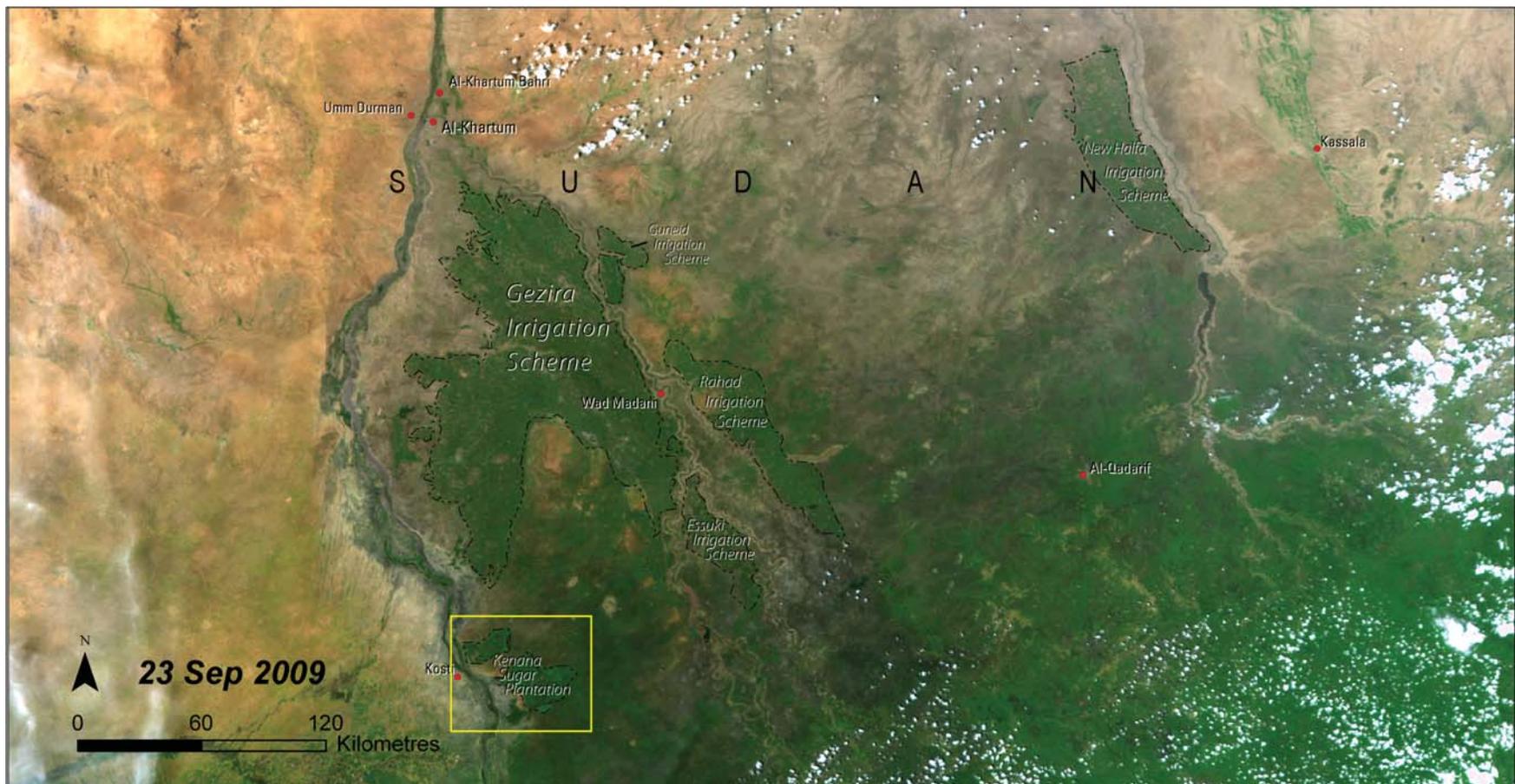
Merowe dam in north-central Sudan near the Nile's fourth cataract is among Africa's largest hydroelectric projects. When complete, it will generate nearly 6 000 GWh of electricity annually and will have the potential to irrigate around 400 000 ha of crops

(Lahmeyer Int n.d.). Even by regional standards, Sudan is in dire need of greater electricity generating and distribution capacity to support much-needed development (Moussa and Bethmann 2007). However, the human, environmental and archeological costs of the Merowe Dam have been substantial and have raised complaints from NGOs and the UN (EAWAG



2006, IR n.d., UN News Centre 2006). It has been reported that when the dam began filling in August 2006 (IR 2006b), it affected 10 000 families forcing tens of thousands of people to relocate their homes and livelihoods (Hildyard 2008). The dam submerged a substantial area of agricultural land, as can be seen in the high resolution satellite image from January

2007 (Inset B, Figure 2.8.9), 18 months before the dam was closed. Like many of the Nile Basin countries, Sudan has considered plans for several dams along its length of the river (Independent 2008, UNEP 2007). The most controversial of these has been the Kajbar Dam proposed for the Nile's second cataract.

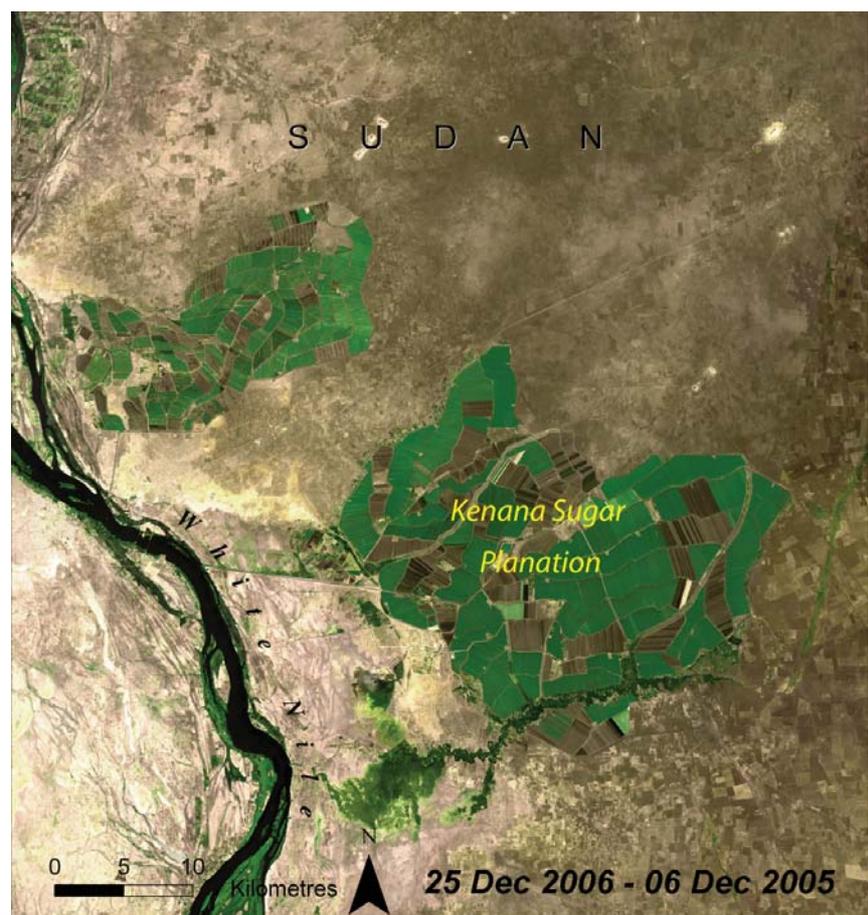


**Figure 2.8.10: Sudan has the second-highest amount of land under irrigation in Africa after Egypt, including the massive Gezira Irrigation Scheme built in the early 20th century**

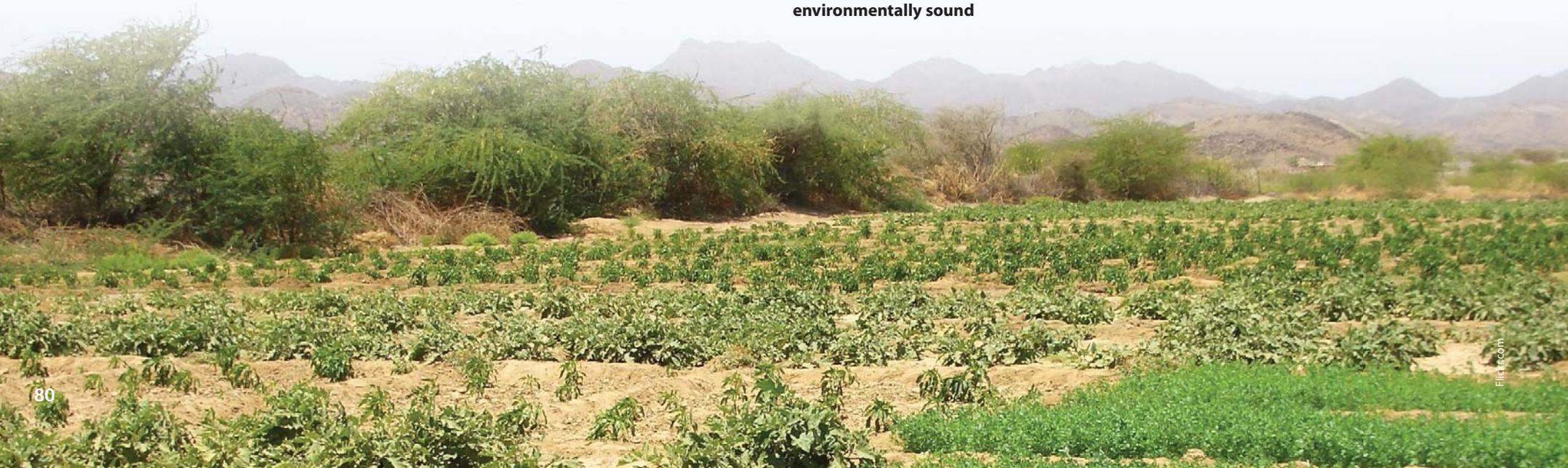
### Sudan Irrigation

Sudan has an estimated 48 000 km<sup>2</sup> of land with irrigation potential, but water limitations constrain the area that can actually be developed. Currently, 16 800 km<sup>2</sup> is under large-scheme irrigation and a total of just under 20 000 km<sup>2</sup> is irrigated land (Figure 2.8.10). Plans to increase the irrigated area are based on the amount of water that would be available if the Jonglei Canal is completed.

Several problems, including inefficiency and poor maintenance, have reduced the productivity of Sudan's existing irrigation. The Gezira Irrigation Scheme built in the early 20th century is one of the world's largest at nearly 9 000 km<sup>2</sup>. Other schemes such as Rahad, New Halfa and the Kenana Sugar Plantation were built in the 1960s and 1970s (Figure 2.8.10). While the Kenana scheme is generally seen as efficient and environmentally sound, Sudan's irrigation overall is ranked last among the Nile Basin countries in efficiency and use of best practices (Figure 2.8.11).



**Figure 2.8.11: While Sudan has had problems with efficiency at many of its irrigation facilities, the Kenana Sugar Plantation is widely seen as efficient and environmentally sound**



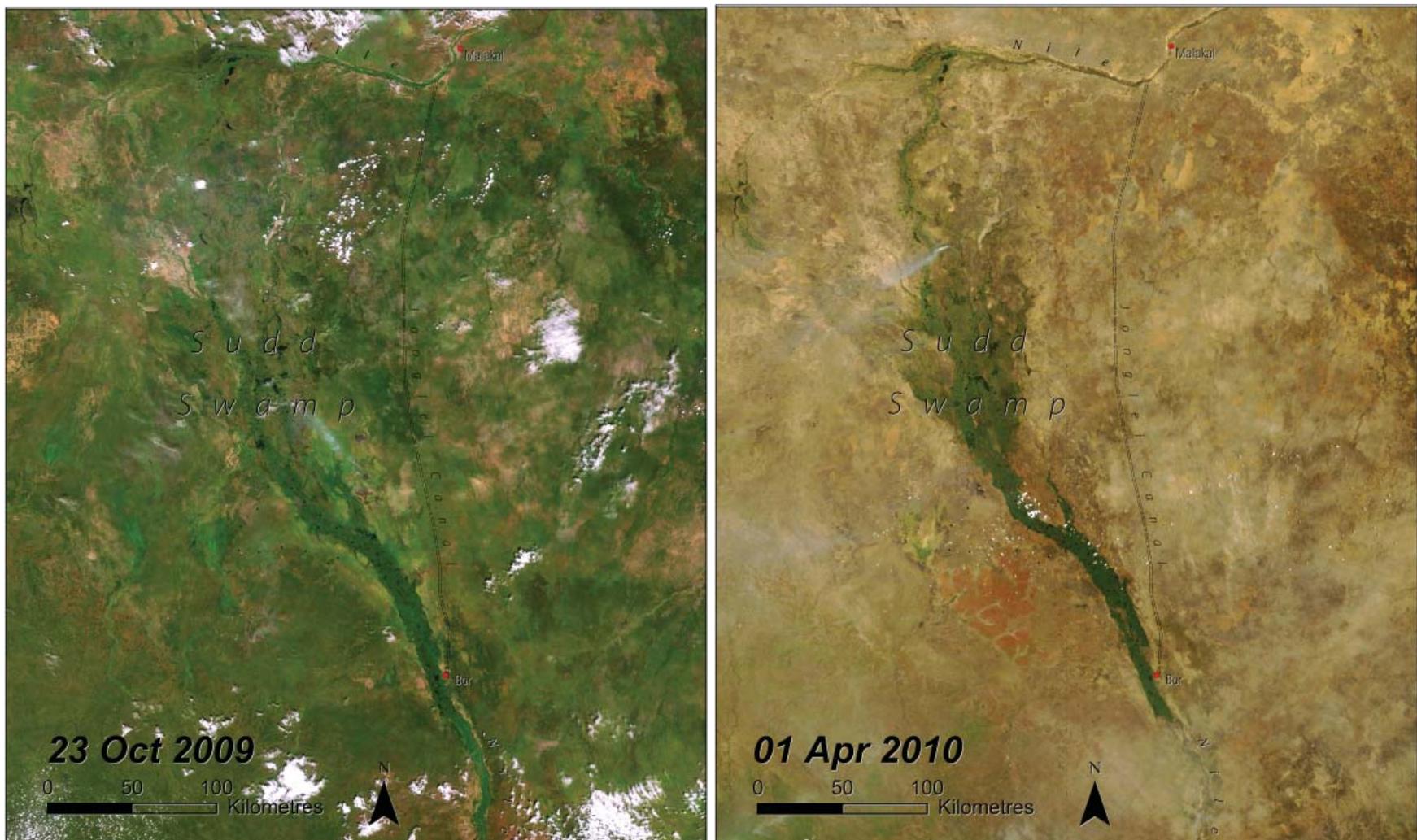


Figure 2.8.12: Wet season and dry season images of the Sudd Swamp. Annual overbank flooding creates an enormous wetland that is an integral part of the local ecosystem as well as the livelihoods of local people



Construction of the canal ended in 1983 and the digger has remained here since

### The Sudd Swamp and Jonglei Canal

The Sudd is a vast wetland in southern Sudan where the Nile River wanders for nearly 644 km, losing much of its flow to evaporation (Howell and others 1988). During the dry season, the wetlands contract to approximately 8 300 km<sup>2</sup> of permanent swamp (Krishnamurthy 1980). During the wet season from April to October, the Sudd overflows into the surrounding area to cover 80 000 km<sup>2</sup>. This annual pattern of flooding is an integral part of the ecosystem and is crucial to the local flora and fauna and to the local Nilotic people's way of life (Krishnamurthy 1980, Laki 1994).

The Jonglei Canal project is designed to reroute a portion of the Nile's flow around the wetland, thus reducing evaporative loss and increasing the water available downstream for irrigation. The project has been at a standstill since November 1983 when military conflict in the area stopped construction (Laki 1994). This conflict has now ended and there are plans to resume construction.

A 1954 study, *The Equatorial Nile Project and its Effects on the Anglo-Egyptian Sudan*, identified many concerns with the Jonglei Canal that are still

a source of controversy today. It concluded that a canal diverting 55 million m<sup>3</sup> of the White Nile's water per day would mean the loss of 36 per cent of pasture and 20 000 metric tonnes of fish. It would also significantly reduce agricultural production (Laki 1994). The pastoralists who depend on the area's seasonal flooding will lose the grasses for their cattle and access to drinking water; in addition, the canals will impede their seasonal migration. Several studies support these concerns and a little-studied second phase of the project will almost certainly further affect the area. Environmentalists have voiced concern that the project could have drastic effects on the ecosystem, potentially affecting the climate, groundwater recharge, water quality, fisheries and the local people (FAO 1997).

The proponents of the canal claim that its benefits will outweigh impacts on the wetlands. In addition to enhancing of downstream irrigation, supporters say that travel from Khartoum to Juba, the main city in the south, will be reduced by 300 km. The impact of this project is difficult to predict and further study is needed to ensure that decisions are based on sound up-to-date science.



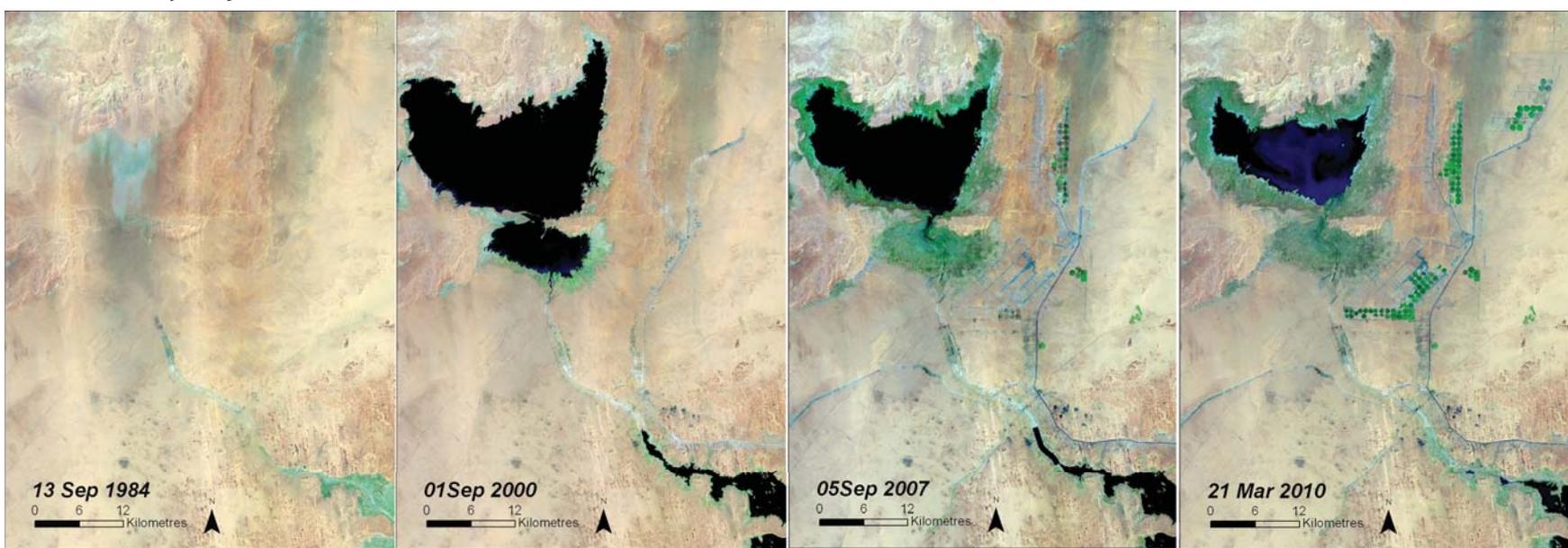
**Figure 2.8.13: Overflow from the Lake Nasser spillway created a chain of enormous lakes in the middle of Egypt's Western Desert between 1998 and 2002 which have since largely evaporated**

### Toshka Lakes

In the mid-1990s, water levels in Lake Nasser on the Nile River approached the reservoir's storage capacity of 183 m above sea-level. Excess water was released through a spillway that flowed into the Toshka Depression in the Western Desert. Over the next several years, continued overflow created a series of lakes on some of Egypt's most arid land.

After peaking at 182 m above sea level in 1998, levels declined and flow through the spillway ceased in 2001. Since that time, levels in the Toshka Lakes have been declining as well—primarily by evaporation and to a lesser degree by infiltration. At the current rate, the remaining water will be lost to evaporation as the lakes disappear in the next few years (Figure 2.8.13).

### The New Valley Project



**Figure 2.8.14: The New Valley Irrigation Project uses water from Lake Nasser to grow crops in the desert including wheat, tomatoes, grapes and citrus. The goal is to irrigate over 3 300 km<sup>2</sup> of desert land and attract settlers away from the densely populated Nile Valley**

In January 1997, the Egyptian government began building a network of canals to continue carrying Lake Nasser water to the eastern portion of the Toshka Depression with the goal of irrigating 3 360 km<sup>2</sup> of land in the Western Desert. The New Valley Project was intended to relieve overcrowding within the densely populated Nile Valley and provide economic development to Egypt.

Among the many challenges the developers faced was the fact that only about ten per cent of the area's soils are suitable for sustained irrigation without extensive management. In addition, the area is prone to wind erosion and dune formation, which present significant constraints on sustainable development and settlement in the area. There is

also a considerable cost to create infrastructure to entice and support the needed labour away from the less challenging Nile Valley area.

The project is an enormous undertaking with a cost of over US\$1 billion. Critics are concerned that the anticipated withdrawal of five billion cubic metres of water per year will reduce water available to farmers on the delta, leave Egypt more economically vulnerable to drought and reduce resources available for other development opportunities. Much of the needed infrastructure is already in place and crops are already being produced, including grapes, cantaloupe, tomatoes, cucumbers, citrus fruits, and wheat.



**The Mubarak Pumping Station pumps water from Lake Nasser into the irrigation channels**





### The Fishery

Lake Victoria has the most important inland fishery in Africa (Njiru and others 2008). Historically, the lake supported a large variety of native fish including hundreds of *haplochromine cichlid* species (Baskin 1992). The release of non-native, predatory Nile perch in the lake in 1954 and its later deliberate introduction in 1962 led to a rapid decline in the endemic haplochromine species and a matching explosion of the Nile perch population in the 1970s and 1980s (Goudswaard and others 2008). The success of the Nile perch experiment led to an economic boom in the fishing industry. The annual catch rose from 30 000 metric tonnes in the late 1970s to 560 000 metric tonnes in the early 1990s (Njiru and others 2008). The benefits of this growth accrued predominantly to larger commercial wholesalers and processors rather than to the small operators, comprised largely of local women, who had historically dominated the fish trade (Njiru and others 2008). The fish catch has declined somewhat since the early 1990s but is still around 500 000 metric tonnes—valued at between US\$300 and US\$500 million per year (Yongo and others 2005).

Fishing is not a major source of food or livelihoods for Sudan with only 1.7 kg of fish consumed per person annually (FAO 2008), although

the sector has been growing steadily for decades. The Nile, along with its tributaries and artificial lakes, are the source of roughly 90 per cent of that production. There are as many as 100 species in the inland fisheries, the most commercially important of which are Nile Perch, Black Nile Catfish, and Silver Catfish. Most fishing is small-scale artisan activity using gillnets, seine nets, long lines, cast nets, and baskets (FAO 2008).

Egypt has significant marine and freshwater fisheries. Its inland fisheries are generally associated with the Nile, including the river itself, some brackish coastal lagoons, irrigation canals, and the reservoirs on the Nile, the most significant of these being Lake Nasser (FAO 2008). The inland fisheries account for almost 70 per cent of the country's total catch. The most economically important species are tilapia, catfish, and the Nile perch (FAO 2008). Egypt's fish capture production has declined somewhat since it peaked at over 400 000 tonnes in the late 1990s and early 2000s (FAO 2008).

### Water Quality

Agricultural runoff, industrial waste and untreated municipal and domestic waste have led to seriously degraded water quality in Lake Victoria over the past few decades (Scheren and others 2000, USAID 2009) (Figure 2.8.15). While industrial waste is generally confined to urban areas (Kampala, Mwanza, and Kisumu among others), untreated sewage and agricultural runoff occur all along the heavily populated shoreline. Phosphorous, and to a lesser extent nitrogen from untreated waste, put excessive nutrients into the water driving algae blooms and contributing to the water-hyacinth invasion seen in the mid-1990s (Scheren and others 2000, Williams and others 2005, Albright and others 2004). In addition, accelerated erosion from deforestation and agricultural conversion of natural areas has led to greatly increased sediment loads being carried into the lake (Machiwa 2003).

As the river flows through Sudan it also picks up substantial non-point source agricultural and urban runoff (NBI 2005a). While water quality has generally been found to be within World Health Organization standards (NBI 2005a) there are some localized high chemical pollution concentrations especially in the Khartoum area (NBI 2005a).

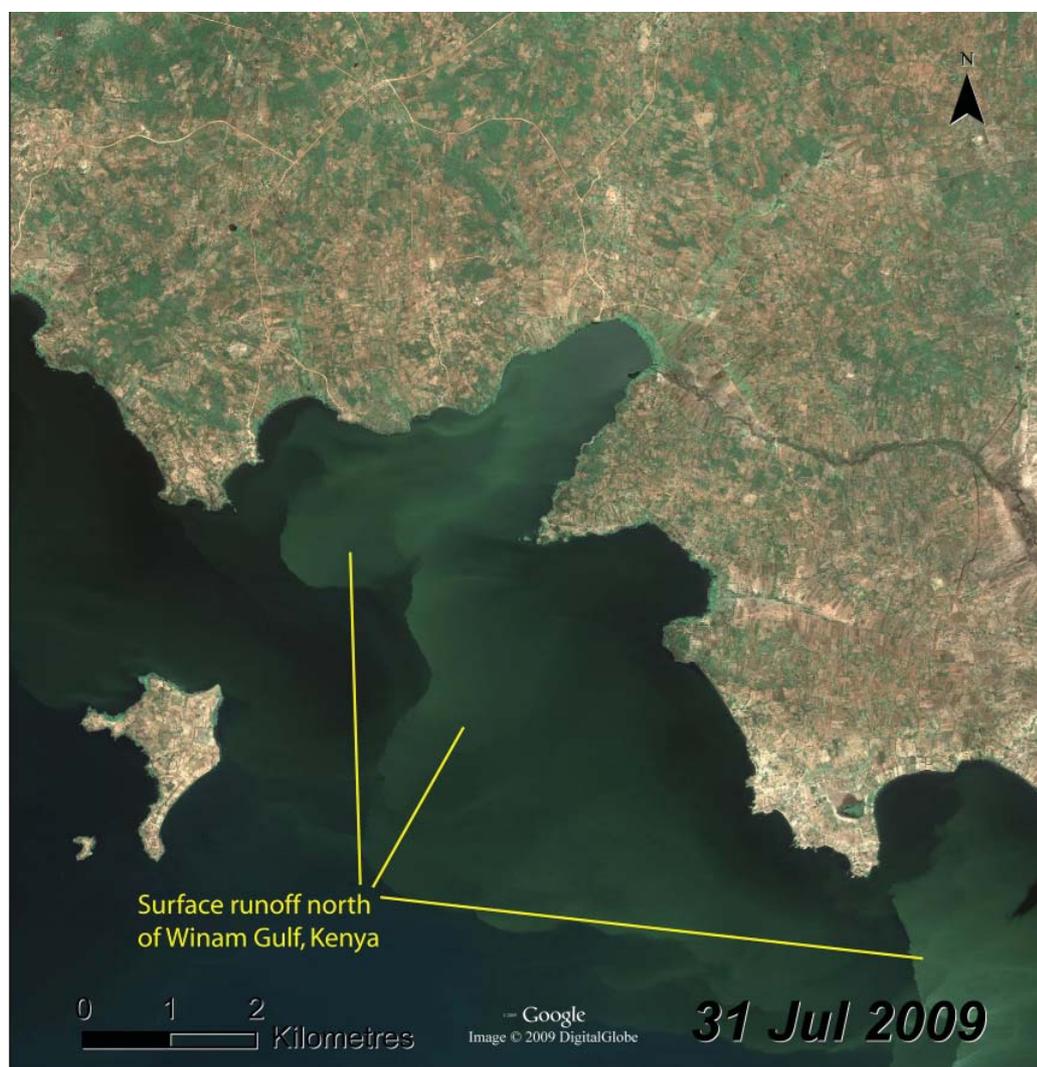
**Figure 2.8.15: Surface runoff from the Entebbe area south of Kampala can be seen as greenish clouds expanding out into the water. Heavy runoff of domestic, industrial and agricultural waste as well as eroded soil is degrading the water quality of Lake Victoria**



In Egypt, water quality is under pressure from intense populations and accompanying agricultural and industrial activity concentrated along the banks of the Nile. In Upper Egypt, this comes primarily from agro-industries particularly sugar cane (NBI 2005b, Wahaab 2004). Downstream, where populations are more concentrated, a wide range of industrial pollution and wastewater enters the river from Cairo and Lower Egypt's other urban centres (NBI 2005b, Wahaab and Badawy 2004). While Egypt has made significant efforts to construct additional wastewater treatment capacity, population growth has outstripped capacity and considerable domestic wastewater enters the Nile with no treatment (NBI 2005b). Intense agriculture and some mixing of industrial and domestic wastewater in irrigation-drainage canals are a source of multiple contaminants in Lower Egypt (NBI 2005b).

### Invasive Water Hyacinth

Water hyacinth is an invasive aquatic plant originating in South America. It first appeared in Lake Victoria in 1989 and subsequently invaded much of the lake's shoreline over the next seven or eight years with the heaviest infestations occurring along the north shore and in Winam Gulf in Kenya (Williams and others 2005, Albright and others 2004) (Figure 2.8.16). The infestation reportedly caused several serious problems including fouled drinking water, clogged city-water intakes, impeded fishing and boating, altered fish populations, fish kills, reduced tourism, increased mosquito habitat and clogged drainage ditches, irrigation canals and culverts (Cavalli and others 2009, Williams and others 2005). Physical removal and limited chemical controls proved inadequate in reversing the invasion (Albright and others 2004). In December 1996, a weevil that feeds on the hyacinth was introduced as a biological control agent (Williams and others 2005). By the late 1990s, the weed began a rapid decline and was largely eradicated by early 2001 (Albright and others

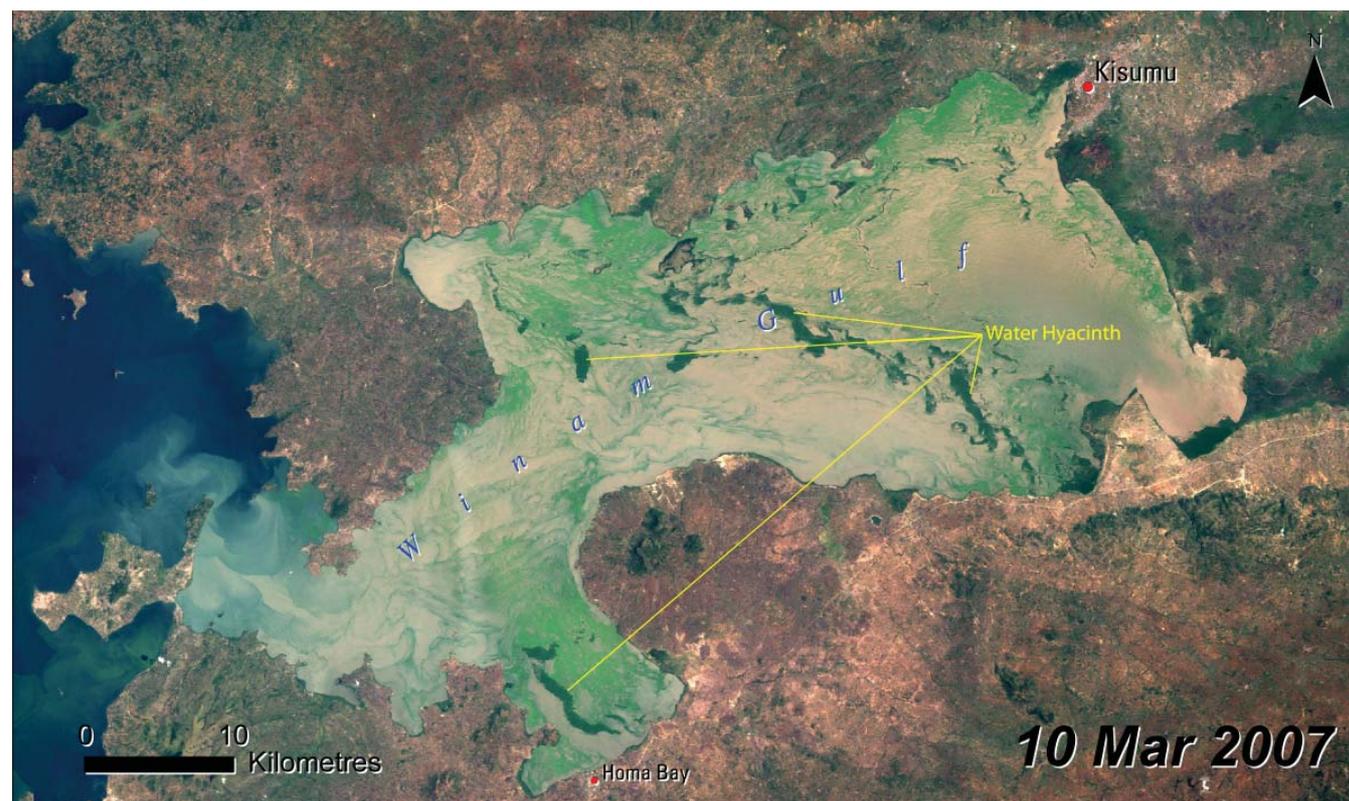


**Figure 2.8.16: The dense rural population just north of Winam Gulf in Kenya increases the eroded soil, agricultural runoff and domestic waste that run into Lake Victoria**

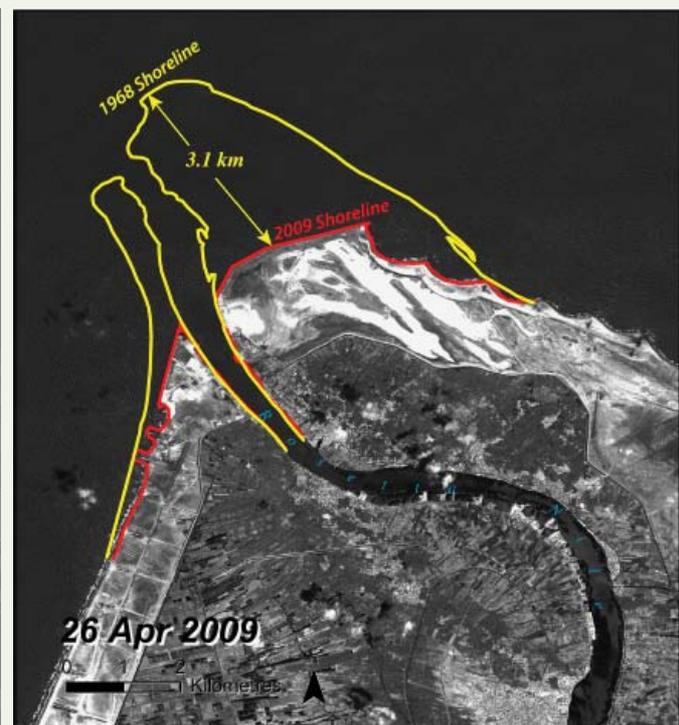
2004). The causes of the rapid decline are not clear but likely include several factors in addition to the weevils, including changed weather conditions from the El Niño Southern Oscillation (ENSO) event of 1997 and 1998 (Williams 2007).

In 2006, water hyacinth was beginning to return to some of the areas affected by the 1990s invasion. Winam Gulf in Western Kenya saw very heavy infestation in early 2007 (Figure 2.8.17).

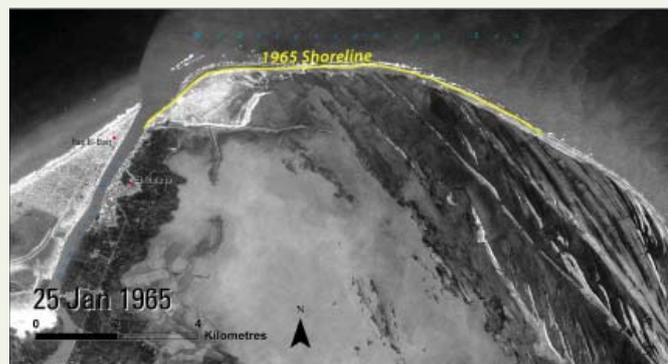
**Figure 2.8.17: Large floating mats of water hyacinth can be seen in Winam Gulf, Kenya in March of 2007**



## Case Study: Coastal Erosion and the Sinking Nile Delta



Rosetta Promontory lost over 3 km to erosion between 1968 (left image, yellow line) and 2009 (right image, red line)



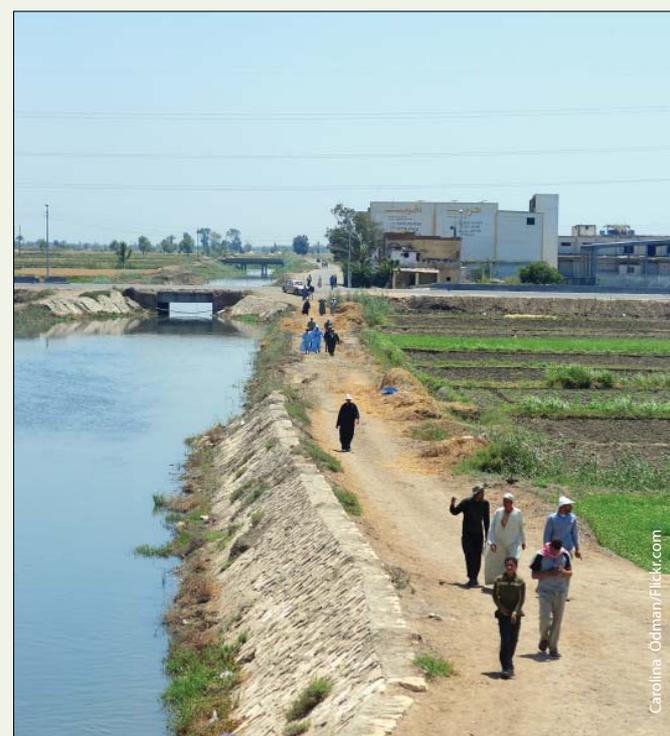
Damietta Promontory, formed by one of the two principle outlets of the Nile River, eroded 1.5 km between 1965 (yellow line) and 2008 (red line)

The Nile Delta is built of sands carried to Egypt's Mediterranean coast by the Nile River, primarily since the end of the last ice age. Dams along the river and sediment trapped in a vast network of irrigation canals have led to a dramatic decrease in the flow of water and sediment to the delta's edge. Since the closing of the Aswan High Dam in 1964, the forces of erosion have outstripped the balancing effect of sediment deposition (Stanley and Warne 1993).

While there are some local areas of accumulation, on balance the delta is now receding (Stanley and Warne 1993). Damietta Promontory and Rosetta Promontory have eroded dramatically as waves and currents have stripped their sands faster than the river can replenish them. The images show the changes from shortly after Aswan High dam was built to recent years. The point of Rosetta Promontory has receded as much as three kilometres since 1968.

Prior to the construction of the Aswan High Dam, freshwater from annual floods influenced salinity and circulation patterns up to 80 km offshore from the delta (El Din 1977). In contrast, current discharge patterns allow salt water from the Mediterranean to reach dams up to 26 km inland (Frihy and Lawrence 2004). Diminished freshwater and sediment delivery to the delta also affects the ecology of coastal lagoons and soil fertility. In

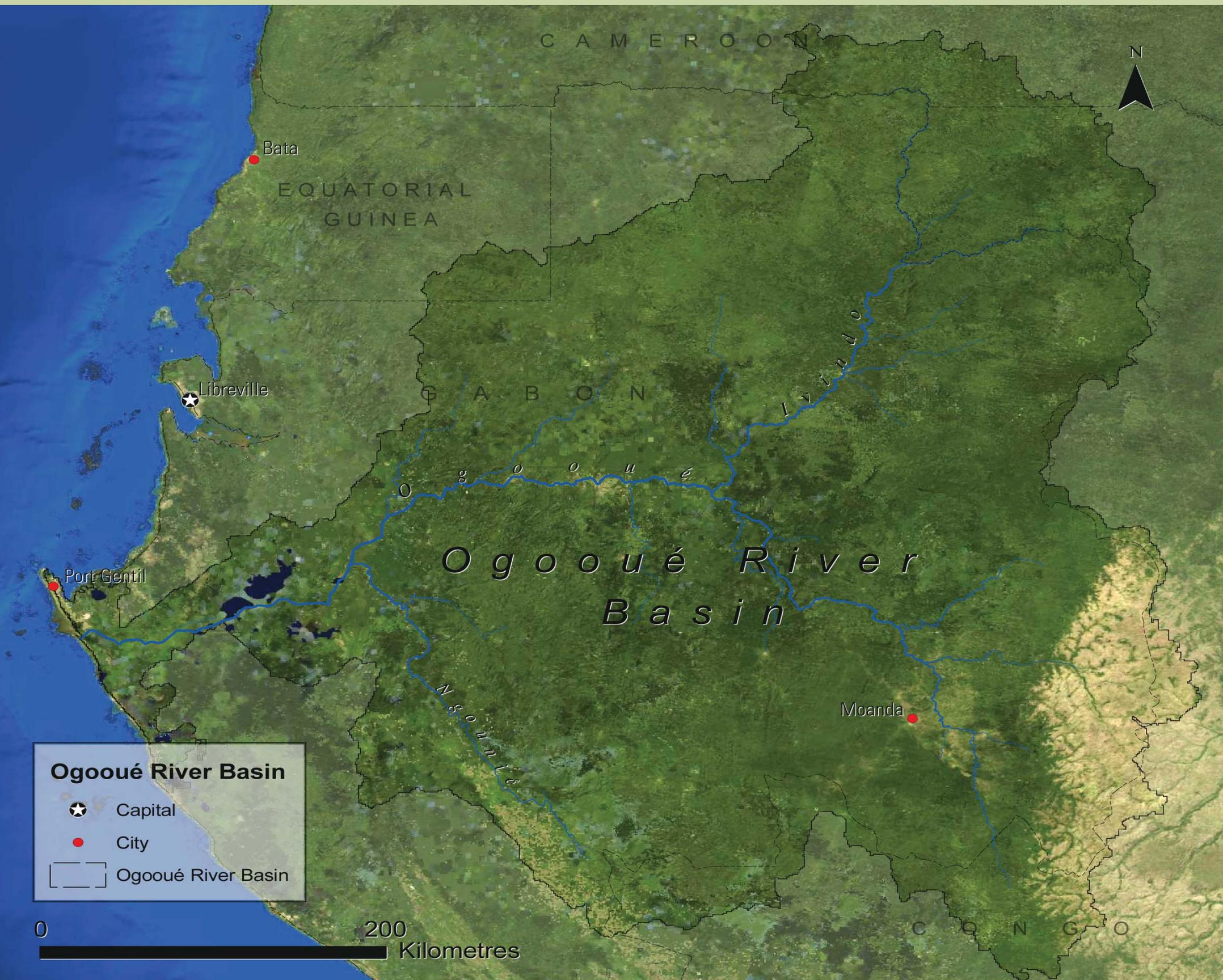
addition, the delta is sinking as new deposits of soil no longer offset the natural effect of soil compaction. Coastal protection structures, regulated irrigation, and increased groundwater exploitation may mitigate the delta's decline, but the current population growth rate threatens to outstrip these measures.



# Ogooué River Basin



The Ogooué River originates at relatively low elevations near the edges of Gabon. Approximately 85 per cent of the basin lies within Gabon with about 12 per cent in Congo and the remaining area in Cameroon and Equatorial Guinea. The river is fed by a dense network of permanent streams. The two largest tributaries are the Ivindo and the Ngounié.



*Much of the basin's population is concentrated along river courses*

**Precipitation**

Average annual rainfall is heavy throughout the basin exceeding 2 100 mm in a few parts of Gabon and averaging over 1 700 mm in Gabon, Republic of the Congo, and Equatorial Guinea's portions of the basin (Figure 2.9.1, Figure 2.9.2).

**Population**

Approximately 650 000 people live in the basin giving it a population density of less than three people per km<sup>2</sup>. Roughly 80 per cent of the basin's residents live in Gabon with another 12 per cent in Congo and about four per cent each in Equatorial Guinea and Cameroon's portions of the basin (SEDAC 2010) (Figure 2.9.3). Much of the basin's population is concentrated along the basin's river courses, particularly so in Gabon where French colonial policy relocated villages and towns along major roads and rivers (Laurence and others 2006).

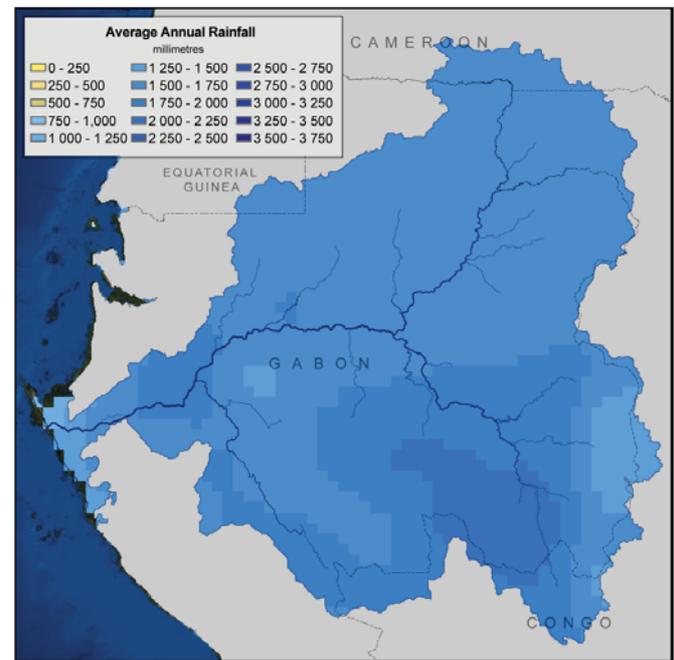


Figure 2.9.1: Ogooué River Basin average annual rainfall

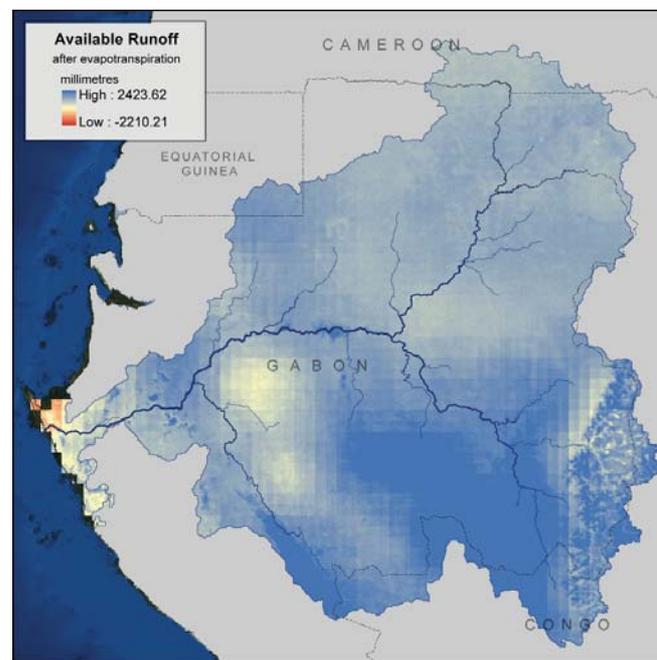


Figure 2.9.2: Ogooué River Basin modeled available runoff

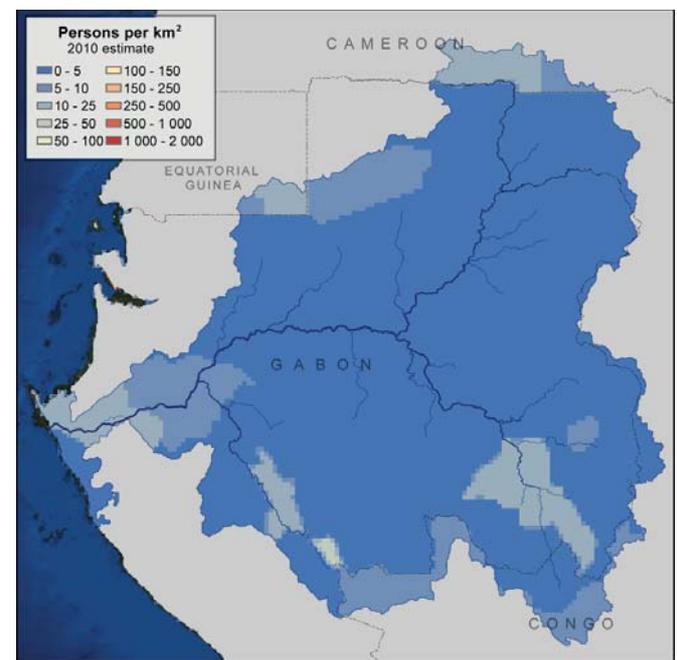


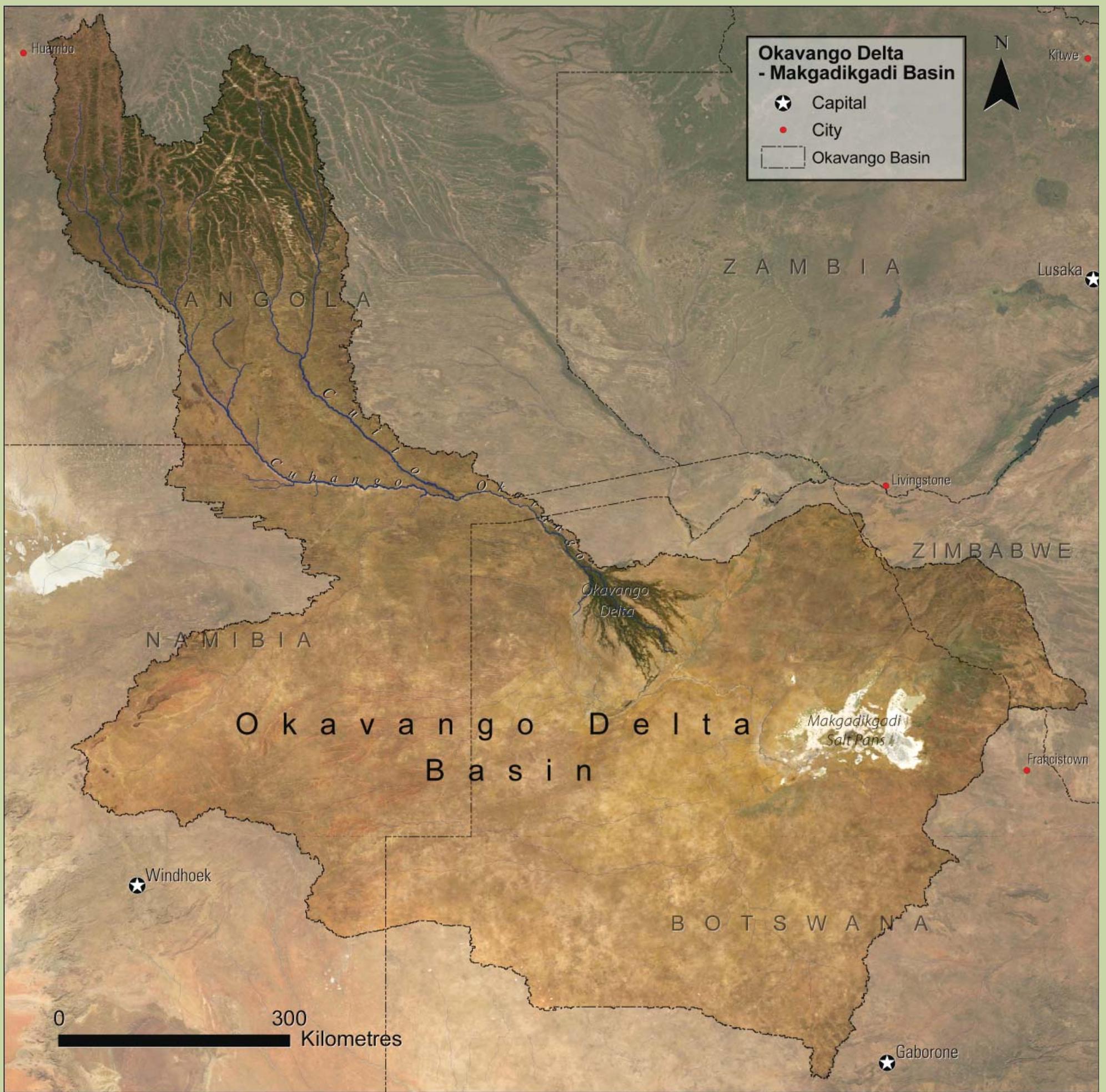
Figure 2.9.3: Ogooué River Basin population density



# Okavango Delta Makgadikgadi Basin



The Okavango Delta Basin is a sub-catchment of a larger drainage basin that empties into the Makgadikgadi Salt Pans. The pans are only seasonally flooded, however, and the majority of the basin's water resources are within the Okavango system.



*There are no major dams on the Okavango's tributaries and no significant water diversions*

Outflow from the Okavango Delta to the Boteti River and the Makgadikgadi Pans is minimal since about 98 per cent of its water is lost to evapotranspiration (Gieske 1997).

Almost all of the inflow to the Okavango Delta comes from the Cubango and Cuito Rivers that capture rains in the more elevated Miombo woodlands of south-central Angola. There are currently no major dams on the Okavango's tributaries and no significant water diversions (Scudder 2008). Proposals to build a dam at the Popa Falls site in Namibia have apparently been shelved following a pre-feasibility study that found that the high cost outweighed the benefits (SAIEA 2009).

The Okavango Delta is among the most valuable wetlands in the world (Scudder 2008) with an extraordinary rich variety of terrestrial and aquatic habitat (Ramberg 2006). The variety and variability of habitat created by the unique hydrological patterns of the Okavango Basin have played a primary role in giving rise to and sustaining its myriad species—1 300 plant, 71 fish, 33 amphibian, 64 reptile, 444 bird and 122 mammal (Ramberg 2006).

**Population**

Population is sparse across the Makgadikgadi-Okavango Basin, averaging just over two persons per km<sup>2</sup> for a total basin population of less than 1.5 million. One-third of these people live in Angola. Another third live in Botswana, spread across a much larger area with a population density of approximately 1.2 persons per km<sup>2</sup>. There are no large cities within the basin (Figure 2.10.1).

**Precipitation**

More than half of the basin falls in northwestern Botswana where mean annual rainfall is around 425 mm. Very little of this rainfall makes its way into streamflow. Namibia occupies about one-quarter of the basin and receives a little more rain on average and makes a significant contribution to the basin's water budget, accounting for about 18 per cent of the larger Makgadikgadi Basin's total runoff. Angola, with a mean annual rainfall around 940 mm and some locations that receive as much as 1 339 mm of rain each year, contributes the vast majority (over 70 per cent) of the basin's runoff.

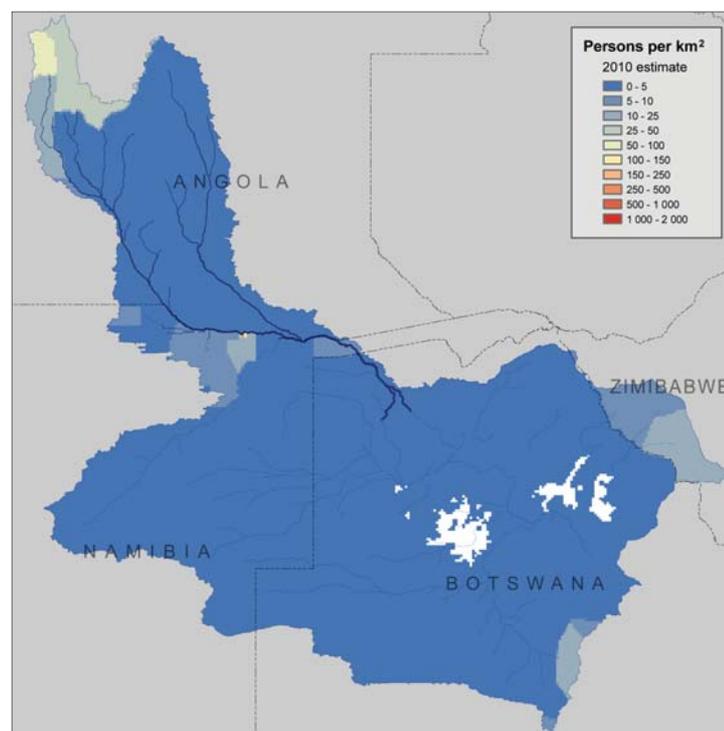


Figure 2.10.1: Okavango Basin population density

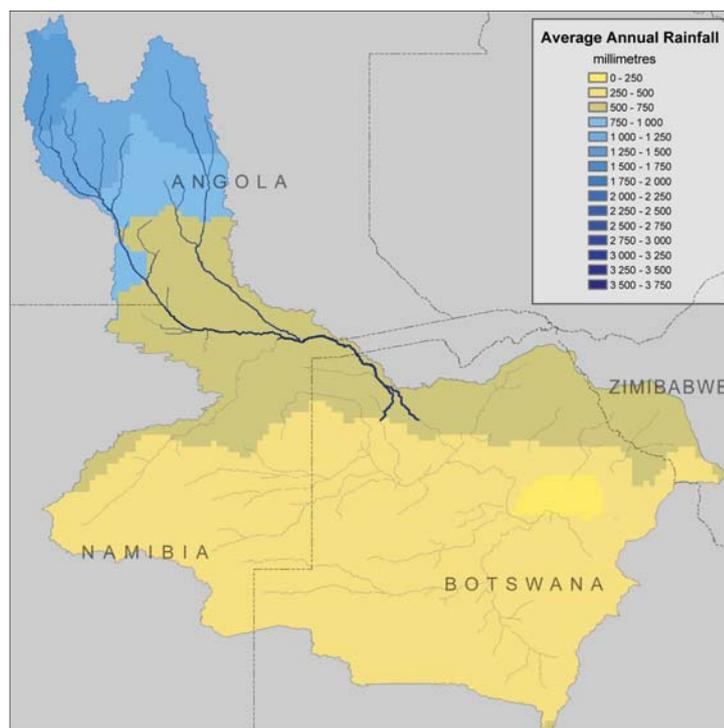


Figure 2.10.2: Okavango Basin average annual rainfall

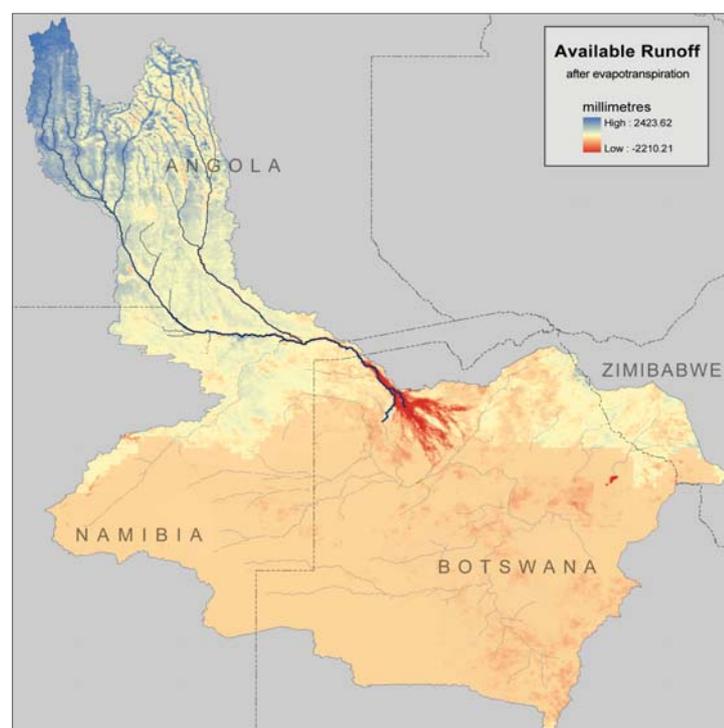


Figure 2.10.3: Okavango Basin modeled available runoff

# Orange River Basin



The Orange River originates in Lesotho where its tributary, the Senqu, begins high in the Drakensberg Mountains. While only three per cent of the basin lies in Lesotho the country's highlands have some of the highest mean annual rainfall in the basin and Lesotho contributes nearly 17 per cent of the Orange River's water budget (Senay and others 2010).



*While only three per cent of the basin lies in Lesotho, the country's highlands contribute nearly 17 per cent of the water budget*

The Vaal River drains the wetter eastern portion of South Africa, which occupies 60 per cent of the basin and contributes most of South Africa's 76 per cent share of the basin's water. Namibia (25 per cent) and Botswana (13 per cent) each make up significant shares of the basin's area but because of high evapotranspiration of limited rainfall, make only minor contributions to the river's flow.

Precipitation in the basin declines from east-to-west with some areas of Lesotho and South Africa receiving over 1 000 mm of rain annually while western areas of South Africa and Namibia receive less than 200 mm (Figure 2.11.1, Figure 2.11.2)

#### Population

Population also follows an east-to-west gradient with the majority of people living in the eastern third of the basin. Nearly 12 million South Africans live within the Orange Basin, most of them in and around the cities of Gauteng Province. Lesotho's average population density of around 67 persons per km<sup>2</sup> is the highest in the basin. Populations in the Namibia and Botswana portions of the basin are quite sparse with densities near one person per km<sup>2</sup> (Figure 2.11.3).

#### Dams, Irrigation and Development

The Orange River Basin is highly developed, with many dams and transfer schemes, particularly in the South African share of the basin. The largest-capacity dams are the Gariiep and Vanderkloof on the Orange River, the Sterkfont Dam on the Nuvejaars River, and the Vaal Dam on the Vaal River. The Katse Dam and Mohale are the largest dams outside of South Africa. Both are in Lesotho and are a part of the world's largest inter-basin water transfer scheme, the Lesotho Highlands Water Project, which transfers water north to Gauteng Province to help meet the Johannesburg area's rapidly growing water needs (Earle and others 2005). Irrigation developments line the river banks. In the Vaal River catchment's heavily populated upper reaches, large volumes of water are utilized for domestic, industrial, and mining purposes. In the western regions where population is sparse, water schemes draw on the river to provide water for livestock, irrigation, and mining (SADC-GTZ 2007).

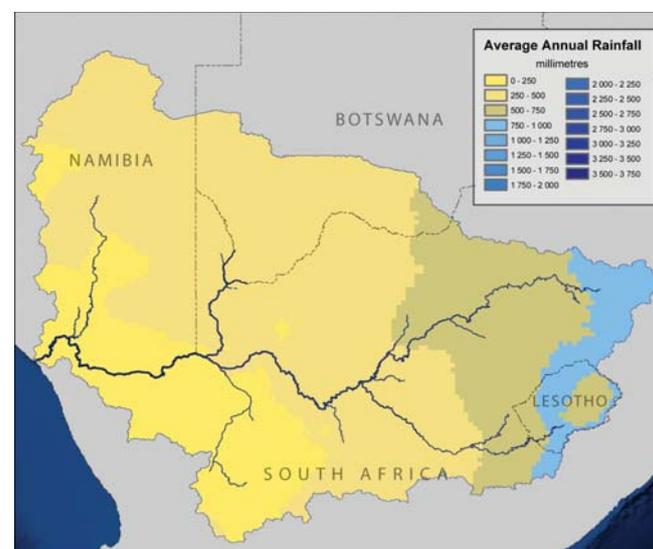


Figure 2.11.1: Orange River Basin average annual rainfall

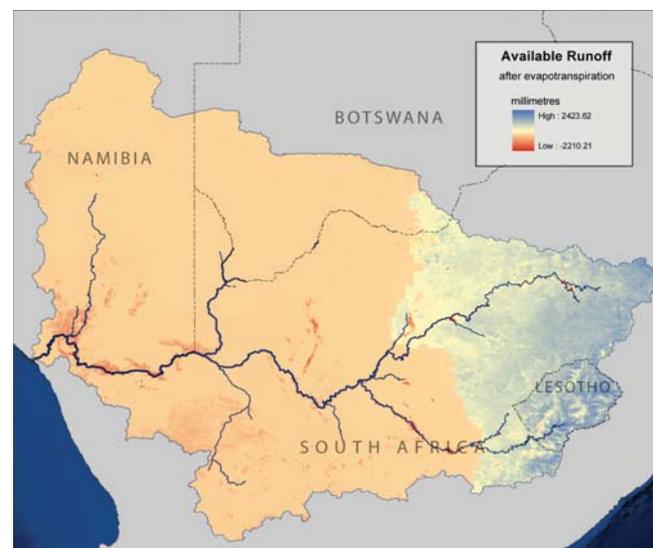


Figure 2.11.2: Orange River Basin modeled available runoff

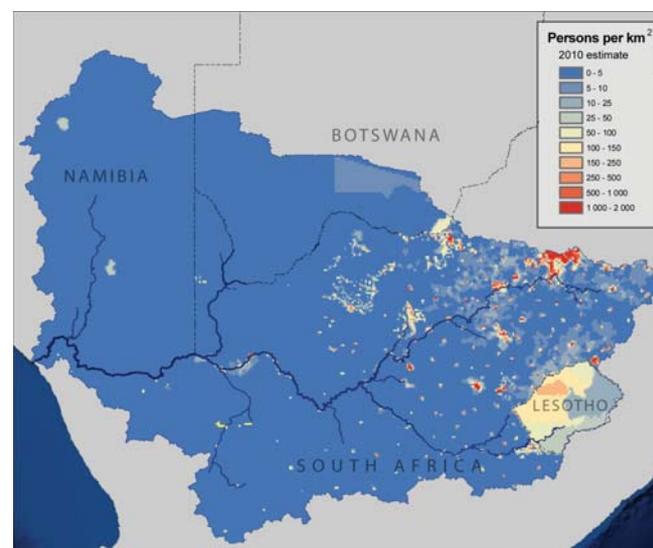


Figure 2.11.3: Orange River Basin population density



# Senegal River Basin



The Senegal River's two primary tributaries are the Bafing and the Bakoye Rivers, both originating in the Guinea Highlands. The Bafing originates in the Fouta Djallon at 800 m and is the source of most of the Senegal's flow. The Bakoye begins on the Manding Plateau about 250 km to the east.



*The river's transboundary nature makes managing the Senegal River Basin's water resources very complex and challenging*

Temperatures rise and rainfall decreases as the two rivers flow north through southern Mali where nearly one-third of the Senegal River's catchment basin is located. The Manantali Dam in Mali retains over 11 000 million m<sup>3</sup> of the Bafing for irrigation and hydropower generation (IR 1999). One hundred and twenty-five kilometres downstream of Manantali Dam, the Bafing and the Bakoye meet to form the beginning of the Senegal River. The river forms the border between Senegal and Mauritania for the rest of its journey to the Atlantic Ocean. Roughly half of the river's basin lies in Mauritania where rainfall is very limited. The river accumulates the flow of several lesser tributaries, including the Gorgol, Karakoro, Kolimbine, Falémé and Ferlo Rivers.

The transboundary nature of the river, the variety of ethnic groups living along its banks, differing rural and urban priorities, conflicting local and national interests, and challenging natural conditions that include limited and highly variable rainfall, conspire to make managing the Senegal River Basin's water resources very complex and challenging.

**Population**

The Senegal Basin's population is approximately seven million. Rural population in the basin is concentrated along the river and its tributaries and includes several ethnic groups including Wolof, Fulani, Tukulor and Moor (Lahtela 2003). The river is an important resource for most of the rural population, supporting pastoral, agricultural and fishing livelihoods. By country, 2.7 million of Mali's population live within the basin, 1.9 million of Mauritania's, and 1.5 million of Senegal's, while less than one million of Guinea's population lives in its seven per cent of the basin (Figure 2.12.1). Population within the basin is growing very rapidly at three per cent per year—high even by West African standards. Urbanization is also high throughout the basin, with many medium and small cities located beside the river itself (UNESCO 2003). According to UNDP's Human Development Index (HDI), many among this growing population are living in difficult conditions. Of the 182 countries ranked on the HDI, Mali ranks 178<sup>th</sup>, Senegal 166<sup>th</sup>, and Mauritania 154<sup>th</sup> (UNDP 2009).

**Precipitation**

At the river's source in the Guinean Highlands precipitation within the Senegal watershed averages over 1 400 mm/yr. As the Bafing and Bakoye Rivers flow out of Guinea and through southern Mali, rainfall remains above an average 850 mm/year. Shortly after the two merge to form the Senegal River, north of Manantali Reservoir, rainfall drops to below 500 mm/yr, a level at which rain-fed agriculture becomes very difficult. Roughly half of the basin lies in Mauritania where rainfall is even more limited. At the far reaches of the Gorgol, Karakoro, and Kolimbine Rivers in Mauritania, average annual rainfall is below 140 mm/yr. Precipitation in Senegal's 15 per cent of the basin averages approximately 500 mm/yr (Figure 2.12.2, Figure 2.12.3).

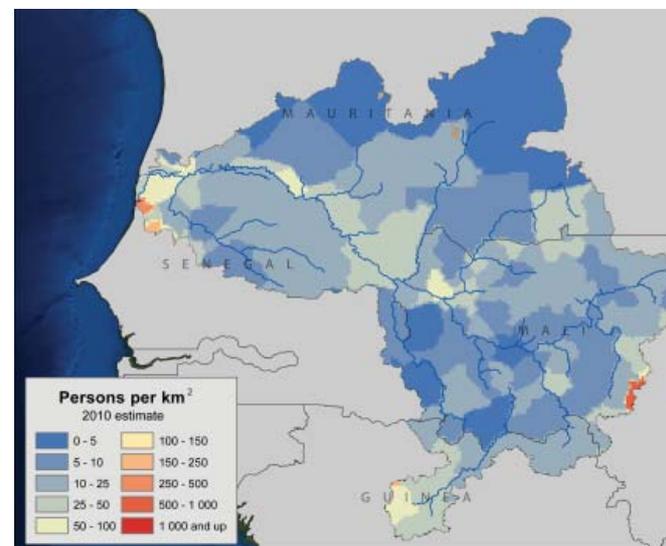


Figure 2.12.1: Senegal Basin population density

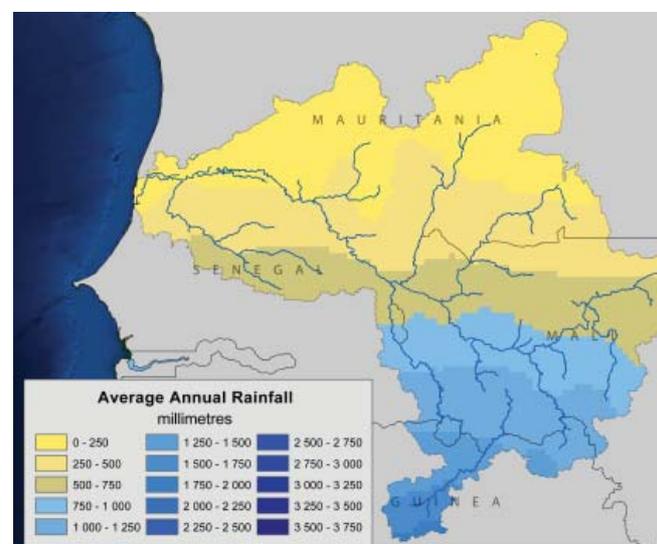


Figure 2.12.2: Senegal Basin average annual rainfall

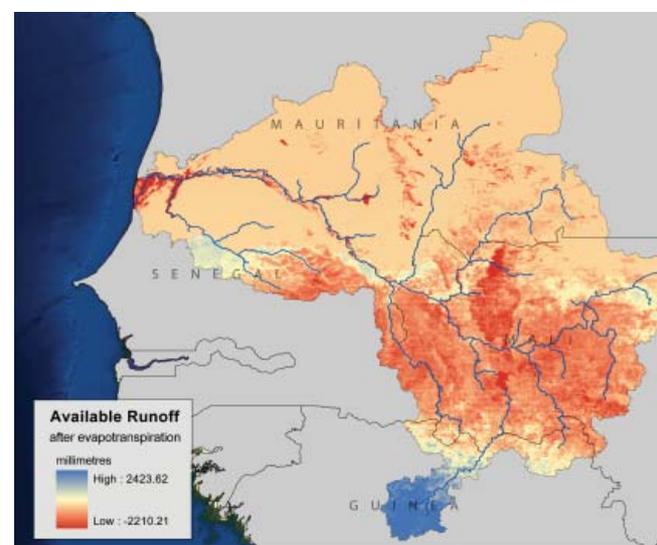


Figure 2.12.3: Senegal Basin modeled available runoff

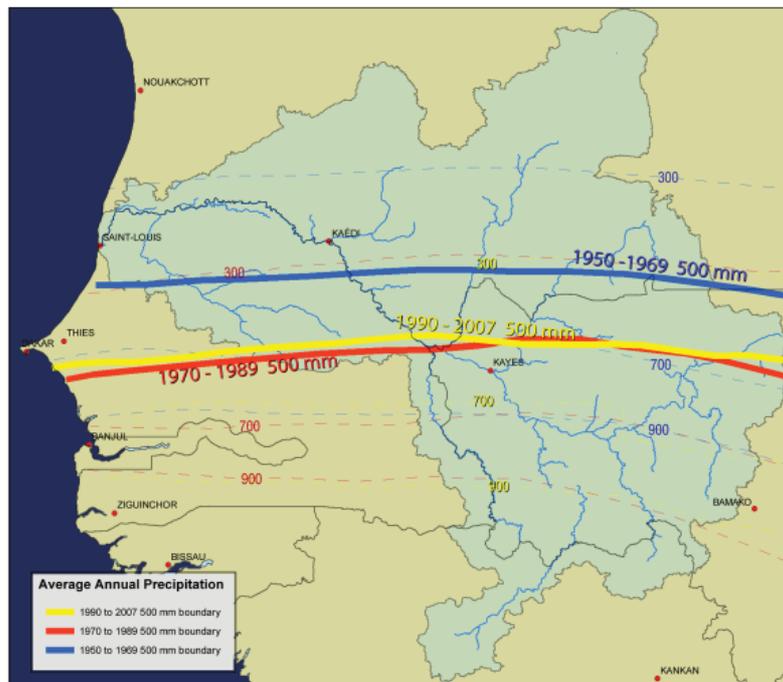
Rainfall along the Sahel is highly variable seasonally, inter-annually and over periods of decades, but on average it declines from south-to-north. During the great droughts of the 1970s and 1980s, this rainfall pattern shifted to the south by approximately 100 km (Lebel and Ali 2009) (Figure 2.12.4). Various studies have conflicting conclusions as to whether the drought has ended although it is clear that precipitation has not returned to levels that occurred during the relatively wet periods of the 1950s and 1960s. This is particularly the case in the western Sahel—including the Senegal Basin—where average annual precipitation over the

past two decades resembles rainfall levels from 1970 to 1989 when the great droughts occurred (Lebel and Ali 2009).

### Irrigation

Large irrigation schemes in the Richard Toll area along the Senegal River in Mauritania and Senegal date back to at least the 1940s and can be seen to cover a significant area at the north end of Lac de Guiers in satellite images from November of 1965 (Figure 2.12.5). The great droughts of the 1970s and 1980s prompted massive investments in large irrigation schemes across the Sahel (Van Asten and others 2003). Rice is the most suitable crop for the soils, climate and available irrigation infrastructure in the Senegal Valley (Verheye 1995) and is the predominant crop on large irrigation developments. Other crops include tomatoes, potatoes, sweet potatoes, onions, melons, okra, maize, and sorghum (UNESCO 2003, OMVS n.d.).

With the construction of the Manantali Dam in Mali in 1981 and the Diama Dam in Senegal in 1986, an estimated 375 000 (OMVS n.d.) to 420 000 ha (FAO 1997) could now potentially be irrigated within the Senegal Basin. Current irrigation development is well below that figure and the area actually cultivated annually is generally well below the approximately 120 000–140 000 ha that are managed for irrigation in Mali, Senegal, and Mauritania (OMVS n.d., FAO 1997). This is generally attributed to inadequate maintenance of drainage and other infrastructure (Connor and others 2008, Verhaye 1995, Van Asten and others 2003, Boivin and others 1998).



**Figure 2.12.4:** In the western Sahel, the northern limit of 500 mm annual precipitation shifted over 100 km to the south between the 1950-1969 period and the 1973-1989 period

With little dissolved salt, the quality of water in the Senegal River is generally good for irrigation. Without proper drainage, however, its alkaline content can accumulate in soils increasing alkalinity in the root zone (Van Asten and others 2003). This is an issue from just upstream of lac de Guiers to just below Kaédi in Mauritania (Wopereis and others 1998). In the delta region, downstream of lac de Guiers, neutral soil salinity and salinity of the water table are the result of interactions with the Atlantic Ocean (Wopereis and other 1998, Barbeiro and others 2004). While this generally provides a good buffer against alkalinization, localized areas of saline soils and the rise of saline water where the water table is near the surface can present problems to irrigation

**Figure 2.12.5:** Areas of large-scale irrigation had already been developed along the Senegal River before 1965



in the delta area. In both cases, proper design of drainage systems and appropriate cropping schedules can mitigate these issues (Wopereis and others 1998).

The benefits of large-scale irrigation developments in the Senegal Basin have not come without significant ecological and human costs. Among those cited in studies of the irrigation projects and related dams are the displacement of thousands of people from their land and traditional livelihoods, alteration of important natural habitats and biodiversity loss, reduced riverine woodlands and unequal benefits distribution (Duvail and Hamerlynck 2003, DeGeorges and Reilly 2006, Horowitz and Salem-Murdock 1993, Tappan and others 2004).

The two satellite images in Figure 2.12.6 show the dramatic changes in a segment of the middle river valley. In 1984, there was considerable irrigation development. Outside of the irrigated areas, the landscape had little vegetation because of the droughts during 1984 and preceding years. During the same season in 2009, areas of irrigation had expanded significantly, identified by the straight lines of bunds, which are built to retain the irrigation water. Abundant vegetation grows outside the irrigated areas as the rains had been more normal in recent years.

Figure 2.12.6: Irrigation development in the Senegal River Basin

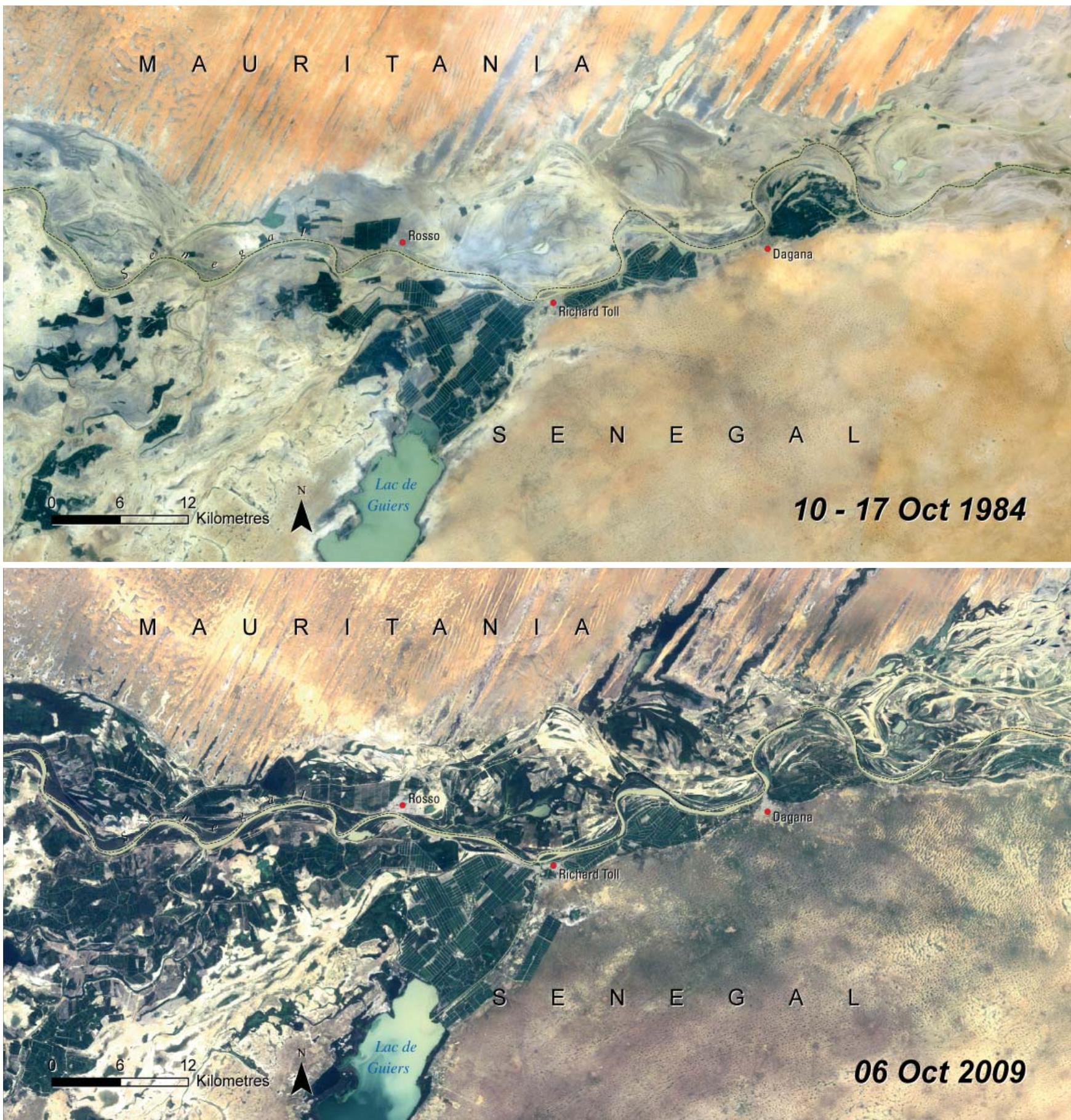
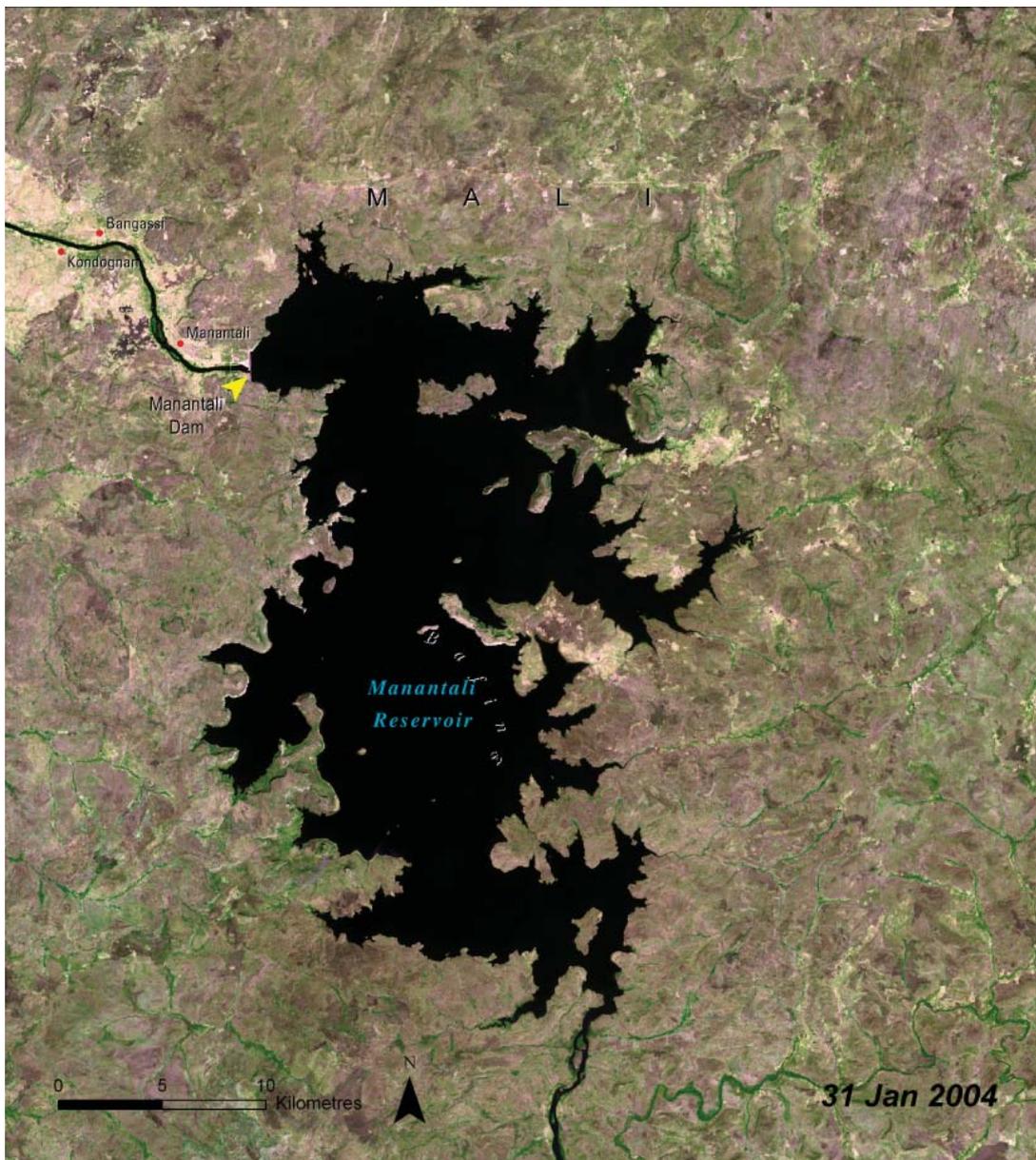


Figure 2.12.7: The Manantali Dam in the Senegal River Basin



### Manantali Dam

Prior to 1981, the Bafing River flowed through western Mali, rising and falling with the seasonal rainfall at its headwaters in the Guinea Highlands. The Manantali Dam in western Mali was one of two large dams built in the Senegal River Basin in the 1980s by the Organisation for the Development of the Senegal River (OMVS). By collecting the highly seasonal waters of the Bafing River, the dam limits extreme floods, stores wet-season flow for irrigation, and provides hydropower to OMVS-member countries (Figure 2.12.7). However, it has also displaced approximately 12 000 people, contributed to the loss of riverine forest along the lower reaches of the river and disrupted traditional flood-recession agriculture (IR 2009, Tappan and others 2004).





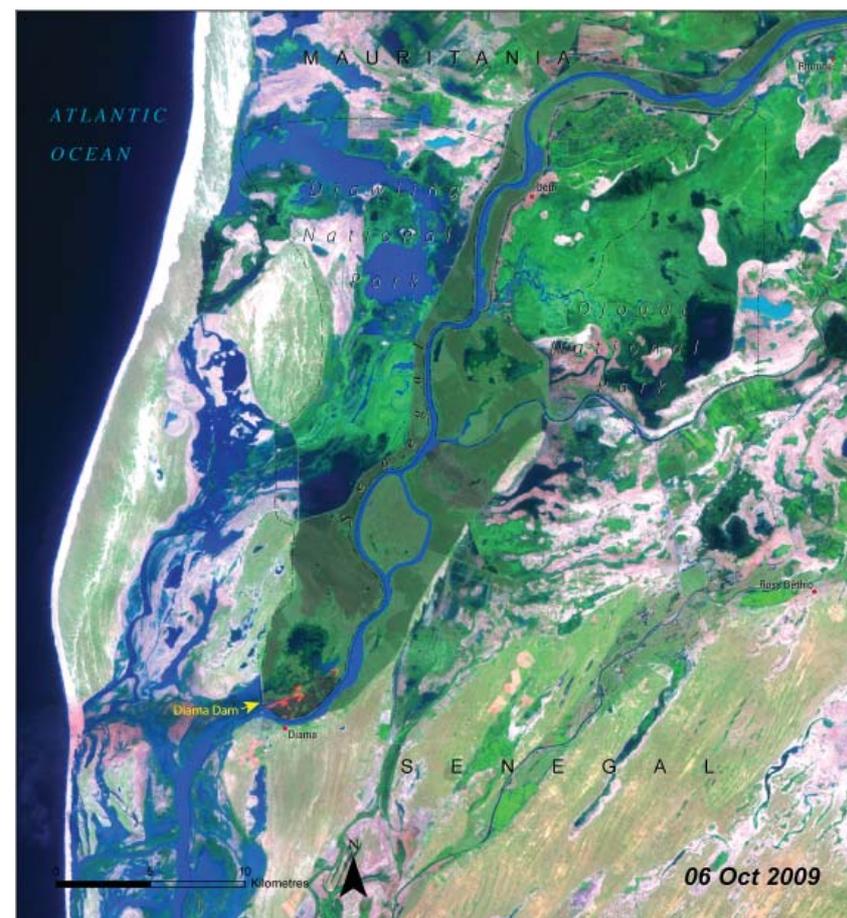
**Figure 2.12.8: Years of drought and the construction of two dams brought the Djoudj and Diawling wetlands to a low point in the 1980s. After changes in artificial impoundments and water flows, the wetlands rebounded**

### Djoudj and Diawling Wetlands

Prior to construction of the Diama and Manantali dams, dry season tides could be detected up to 470 km upstream of the ocean bringing salt water influence up to 300 km inland of the Senegal River mouth (Isupova and Mikhailov 2008). Then, in August of each year during the Senegal River's peak flow, floods would flush much of the delta with freshwater from the annual monsoons (Duvail and Hamerlynck 2003). The alternating brackish and freshwater environment created a unique wetland system that supported rich natural habitats and traditional livelihoods including fishing, grazing, agriculture, and the production of artisanal mat-making (Duvail and Hamerlynck 2003, Fall and others 2003). Natural habitats thrived throughout history under this hydrological regime, including mangroves, saltmarshes, lagoons, acacia woodlands, and floodplain grasses (Fall and others 2003, WMO 2004, Isupova and Mikhailov 2008).

In Figure 2.12.8, the 1984 satellite image of the Diawling and Djoudj area shows the wetlands in decline under the influence of the 1970s and 1980s droughts, which also created a food crisis. The Senegal Basin countries in response to this crisis proposed to develop intensive-irrigated rice production by building two dams on the river. The dams, completed in 1985 and 1988, were to facilitate development of irrigated agriculture, hydropower and river transport, although irrigation in the delta has been less widespread and less productive than planned (Duvail and Hamerlynck 2003, Poussin and Boivin 2002, OMVS n.d., FAO 1997).

The dams also change the delta's natural hydrological patterns with several negative impacts on the natural environment and the local communities that relied on their ecosystem products and services (Duvail and Hamerlynck 2003). In the area of Diawling, fish stocks decreased and much of the wetland vegetation disappeared (Bâ Amadou 2004). Upstream of Diama Dam, the change to an all-freshwater regime led to invasive plant species overtaking much of the natural vegetation (Mietton and others 2007). Invasive species posed such a threat that UNESCO listed Djoudj on its List of World Heritage in Danger (UNESCO n.d).



Beginning in the early 1990s, changes in the hydraulic infrastructure and dam management allowed controlled water releases to better mimic previously existing conditions (Duvail and Hamerlynck 2003b). The wetlands in the Diawling area have substantially recovered. While invasive species in Djoudj continue to be a concern, UNESCO removed Djoudj National Park from its List of World Heritage in Danger in 2006 following mitigation efforts that include biological controls. In the 2009 image, the wetlands on both sides of the river are lush with vegetation following changes in the dams and their operation and a period of improved rainfall.

# Volta River Basin



The Volta Basin lies across parts of six countries in West Africa. Burkina Faso and Ghana each make up approximately 40 per cent of the basin. About eight per cent lies in Togo and the remaining 12 per cent is divided between Benin, Côte d'Ivoire and Mali.



**The Volta Basin  
lies across parts  
of six countries  
in West Africa**



Akosombo Dam

Despite their relatively small area in the basin, Benin and Togo make significant contributions to the river’s water budget by virtue of their location in areas where rainfall exceeds evapotranspiration.

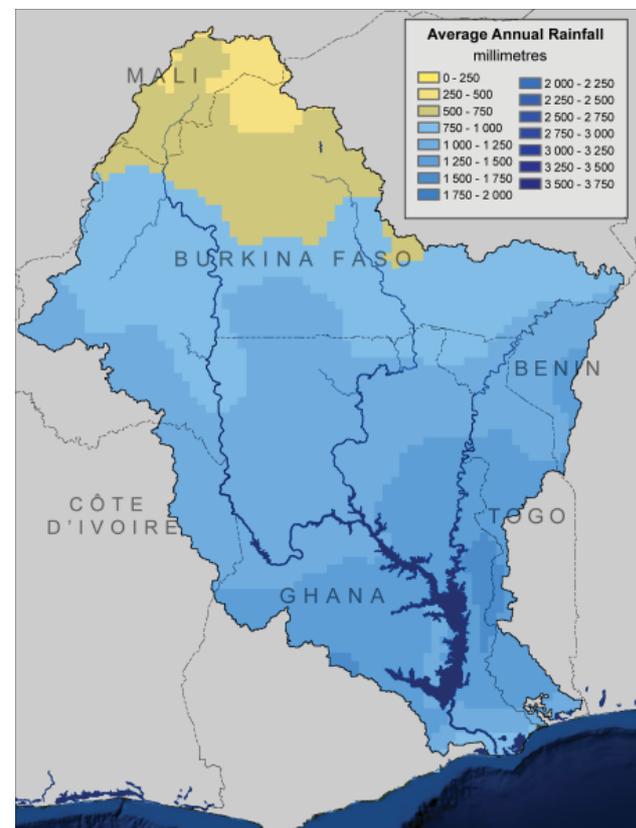
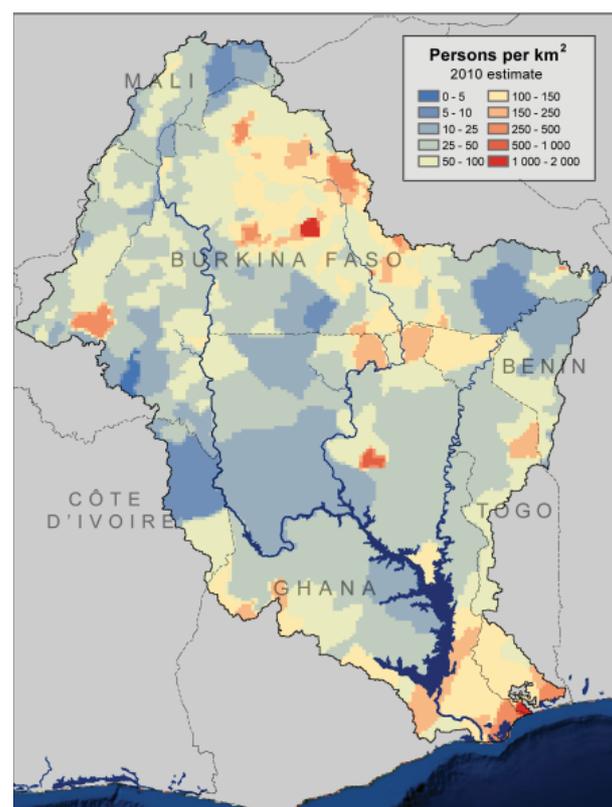
The Volta River has many tributaries but the principal streams feeding its flow are the Oti (Pendjari) River, The Black Volta, Red Volta, and White Volta. The largest of these is the Oti, which originates in northwest Benin where annual rainfall is generally above 1 000 mm. It yields around one-third of the Volta River System’s annual flow (Barry and others 2005). The Black and White Volta Rivers originate in Burkina Faso. Many of the smaller tributaries dry up during arid periods of most years. All of the major streams converge in Ghana and eventually in Lake Volta, the largest man-made lake in the world, formed by the Akosombo Dam built in the 1960s.

**Precipitation**

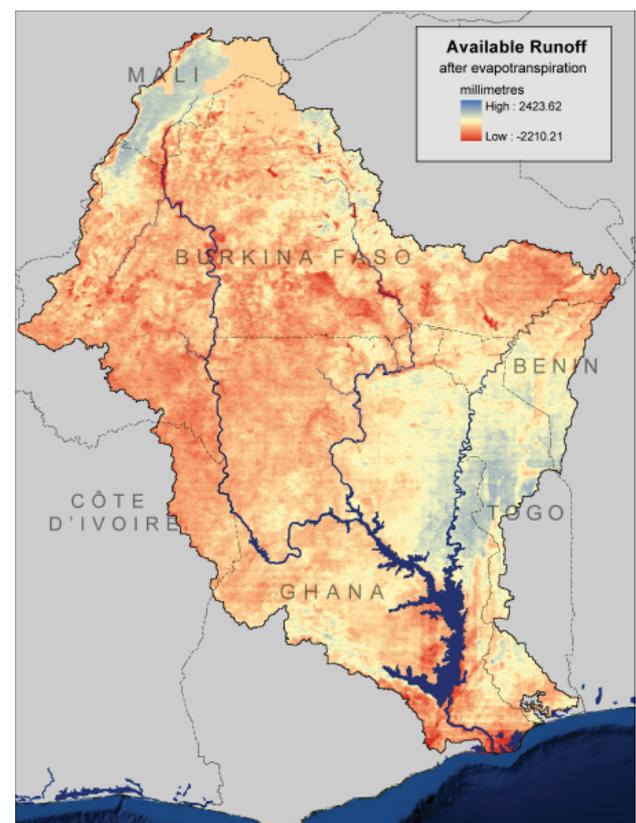
The basin has pronounced wet and dry seasons with two distinct rainy seasons in the more humid south and a single rainy season peaking in August further north (Boubacar 2005). Average annual rainfall generally decreases from south-to-north with areas in eastern Ghana and Western Togo receiving some of the heaviest rainfall—as high as 1 500 mm/yr in some locations. Togo’s portion of the river basin receives the highest mean annual precipitation with an average of 1 262 mm. Ghana also receives over 1 200 mm/yr across its part of the basin. The driest part of the basin lies in Mali at the far northern extreme where rainfall averages about 540 mm/yr (Figure 2.13.1).

High rates of evapotranspiration across most of Burkina Faso and Ghana leave little excess runoff to contribute to the river’s flow. The largest contributions come from Togo and Mali followed by Ghana and Benin. Both Burkina Faso and Côte d’Ivoire have a negative impact on the basin’s water budget due to evapotranspiration rates that exceed annual rainfall (Figure 2.13.2).

**Figure 2.13.3: Volta River Basin population density**



**Figure 2.13.1: Volta River Basin average annual rainfall**



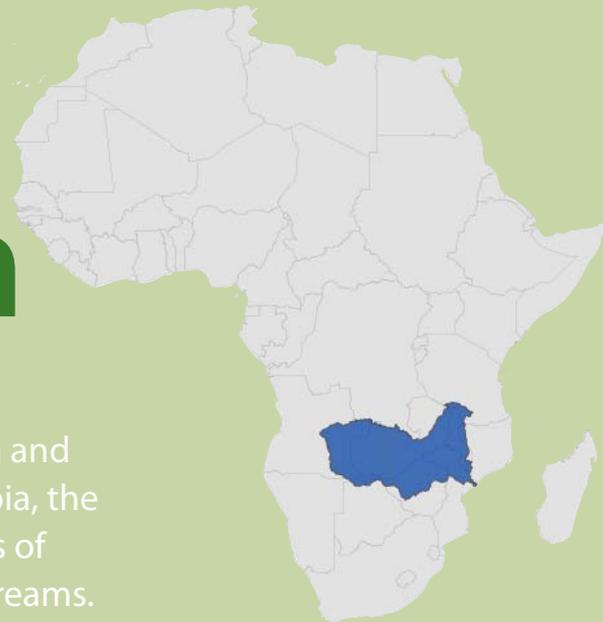
**Figure 2.13.2: Volta River Basin modeled available runoff**

**Population**

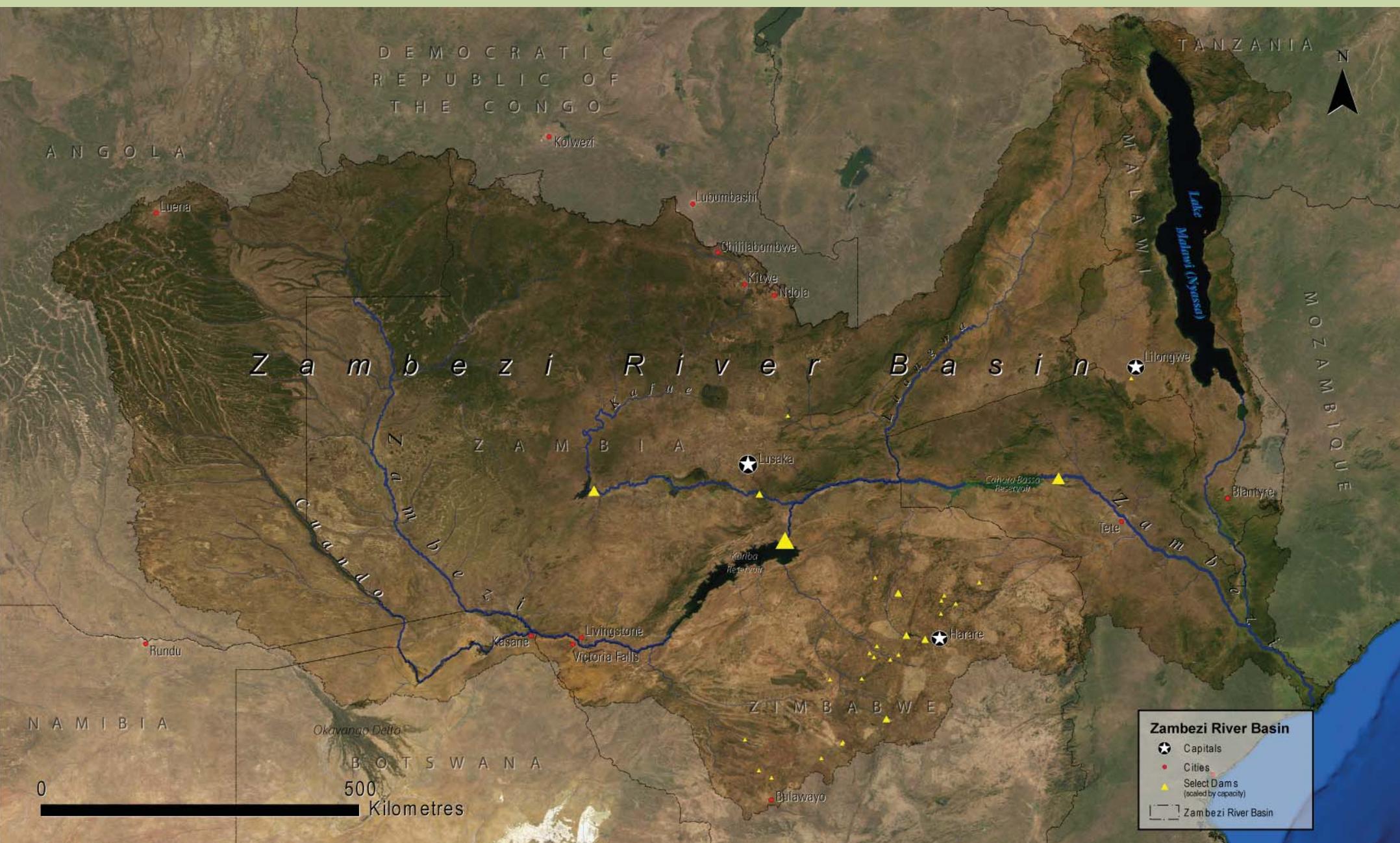
Approximately 28 million people live in the Volta Basin. The two countries with the largest area in the basin also have the most people—Burkina Faso with 13 million and Ghana with almost 10 million people. Togo has the highest population density in its portion of the basin at 116 persons per km<sup>2</sup> while Côte d’Ivoire’s part of the basin has only 26 persons per km<sup>2</sup> (Figure 2.12.3).



# Zambezi River Basin



The Zambezi River begins approximately 1 200 m above sea level in the Kalene Hills, where the borders of eastern Angola, northwestern Zambia and southern DRC meet. As it flows through Angola and northwestern Zambia, the landscape is generally dominated by miombo woodlands with networks of grassy wetlands along drainage lines and riverine forests along larger streams.



## Over 40 million people make their home within the Zambezi basin

Tributaries enter along both banks, draining portions of eastern and southeastern Angola and northern Zambia onto a low-gradient area that forms the Barotse floodplain. Following the Ngonye Falls, the river steepens as it continues to collect tributaries, including the Cuando-Chobe River that drains southern Angola and Namibia's Caprivi Strip. Three hundred kilometres downstream, the river drops a dramatic 100 m forming Victoria Falls and marking the beginning of the river's middle section. Below Victoria Falls, the gradient steepens sharply, the flow accelerates, rapids rise, and the river makes a series of sharp turns for several kilometres (Moore and others 2007). It then widens and continues along the border between Zambia and Zimbabwe, expanding dramatically as it enters Kariba Reservoir. Downstream by 200 km, the Zambezi enters Mozambique and flows into the Cahora Bassa Reservoir. Below this, the gradient levels out again as the river crosses the coastal plain. Below the Shire River, the Zambezi crosses another area of floodplains before reaching the delta and emptying into the Indian Ocean.

### Population

A total of over 40 million people make their home within the Zambezi basin. While only eight per cent of the basin's area is in Malawi, over 13 million people or one-third of the basin's mostly rural population lives there. Both Zambia and Zimbabwe have roughly ten million of their people living within the basin. Several of the region's largest cities and urban agglomerations are within the basin including Lusaka and the copperbelt cities of Zambia as well as Harare and Bulawayo in Zimbabwe and Lilongwe and Blantyre in Malawi. Countrywide growth rates in Malawi, Tanzania, and Angola are high by global standards. Most growth within the basin since 1990 has occurred in Malawi, however, and in the already large urban areas. Malawi's population growth rate peaked in the late 1980s at over six per cent annually but has since declined to a little over 2.5 per cent (Figure 2.14.1).

### Precipitation

Annual precipitation throughout most of the basin is adequate to support rain-fed agriculture. It generally decreases to the south and west from a high of over 1 700 mm/yr in northern Malawi to parts of Botswana, Namibia and Zimbabwe where the average is just over 500 mm/yr. Rainfall is quite variable spatially and from year-to-year, especially in parts of the eastern edge of the basin and particularly in eastern Malawi and western Mozambique. Over 42 per cent of the Zambezi Basin falls within Zambia, and occupies about three-quarters of the country. Zambia's annual average rainfall ranges from over 1 500 mm in some northern areas to the 650 mm range across its southern border. Precipitation averages 950 mm across Zambia's portion of the basin, contributing nearly half of the river's inflow. Angola accounts for

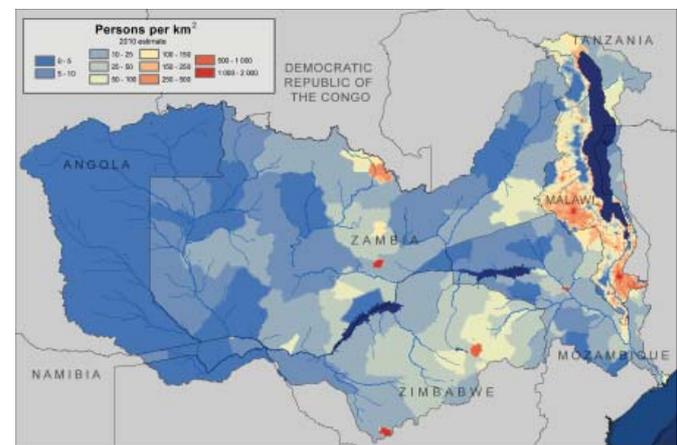


Figure 2.14.1: Zambezi Basin population density

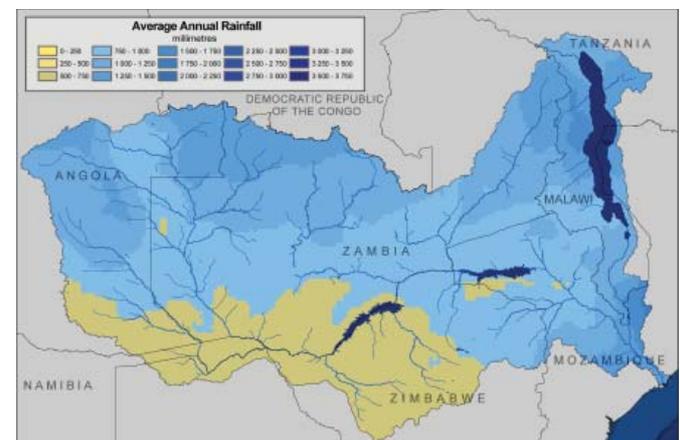
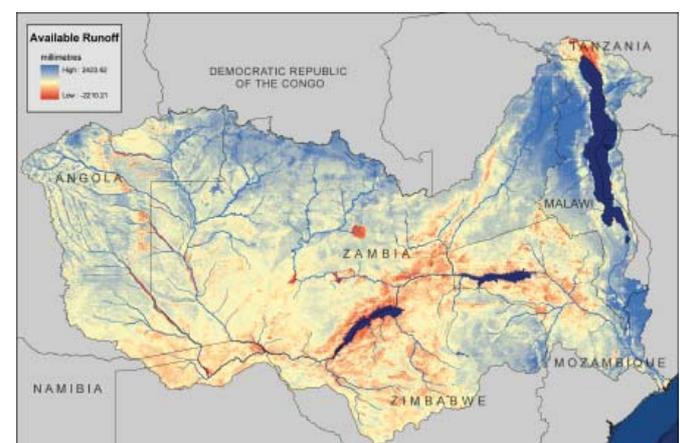
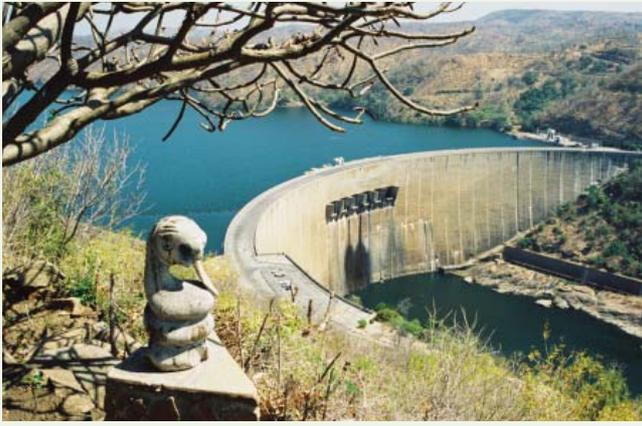


Figure 2.14.2: Zambezi Basin average annual rainfall





Kariba Dam viewed from the Zimbabwe side of the Zambezi

### Kariba Dam

Kariba was the first of the large dams built on the Zambezi River. The river's water began filling it at the end of 1958 (Beilfuss 2006). The dam has an installed power capacity of 1 350 MW and creates a reservoir covering 5 580 km<sup>2</sup> (Magadza n.d.). It is so large that it has increased seismic activity in the valley, causing many

small earthquakes since the lake was filled (Magadza n.d.). The filling of Kariba displaced 57 000 people (ETH 2004, McDermott-Hughes 2006, Scudder 2006). Relocation is generally considered to have been poorly handled leaving most of the displaced much worse off (Magadza 2006, Magadza n.d., ETH 2004, Scudder 2006).

Kariba Dam regularized the river's flow and began changing downstream flooding patterns. This

had a negative impact on several natural systems downstream of the dam, especially wetlands, including the delta area (Scudder 2005, Beilfuss 2006). The loss of natural flooding patterns also adversely affected the coastal shrimp fishery in Mozambique (Scudder 2005). In addition, the reservoir has suffered invasions of *Salvinia molesta* and water hyacinth (Marshall 1981, Magadza 2006).

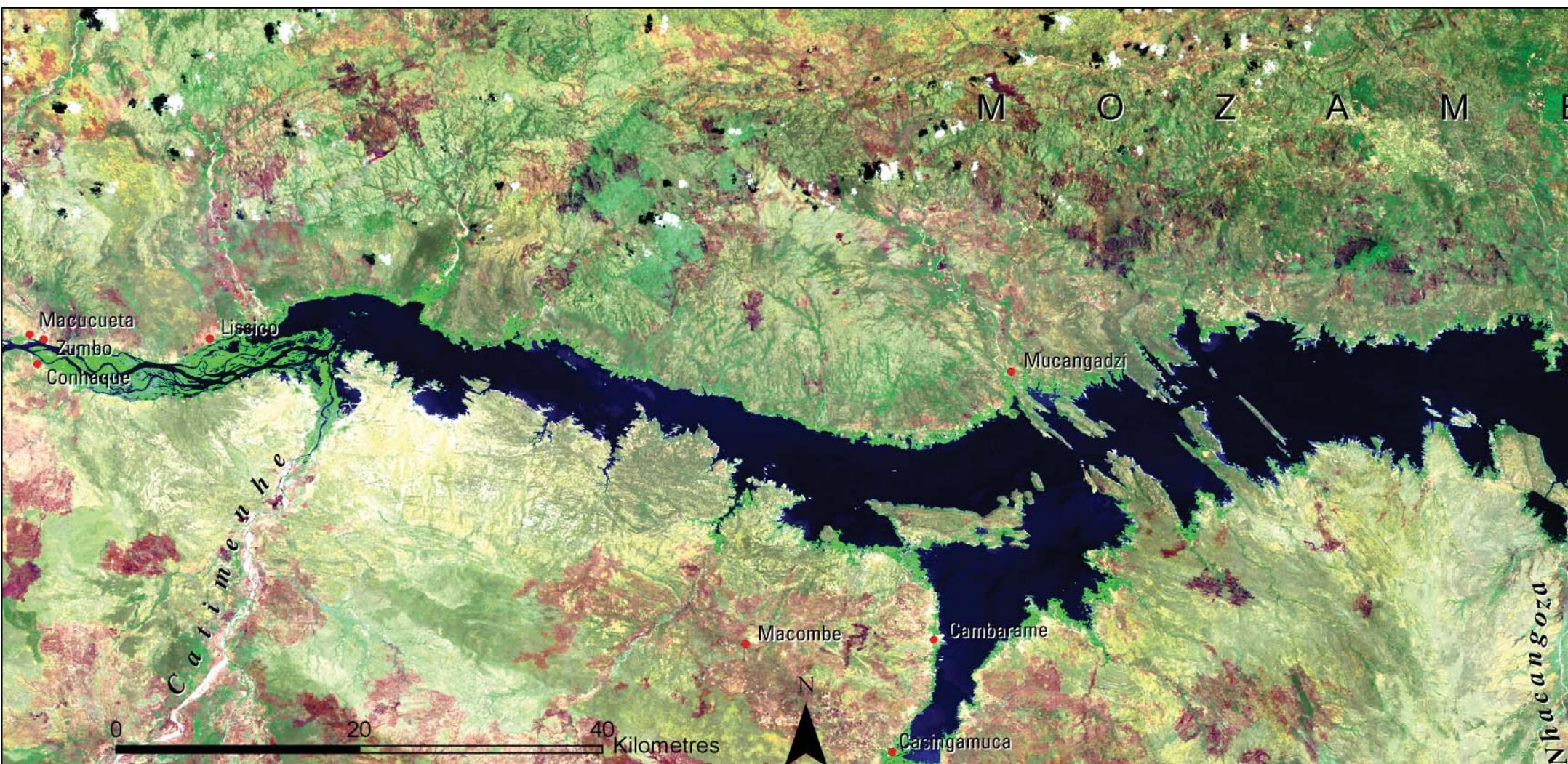
Kariba's power generation has been very important for Zambia and Zimbabwe's development, supporting large industries such as the mines in Zambia's copperbelt (Magadza 2006). In addition, a productive artisanal and industrial fishery has been developed in Lake Kariba (Ngalande 2004). The new large water environment was not ideal for the native fish species and left large parts of the new habitat unutilized. A species of fish from Lake Tanganyika, known locally as kapenta, was introduced into the lake and quickly colonized the open niche (Magadza 2006). While the fisheries benefits have not fallen equally to all groups, the catch has been substantial, averaging around 9 000 metric tonnes between the mid 1980s and 2000 (Ngalande 2004).

### Water Development

Four major dams in the Zambezi Basin regulate the river's flow and generate much of the area's electricity. The Cahora Bassa Dam and the Kariba Dam are on the Zambezi itself, while the Kafue Gorge Dam and Itezhi-Tezhi Dam are on the Kafue River in Zambia—one of the Zambezi's main tributaries. All four dams have generated some degree of controversy regarding

their environmental and human impact (IR 2006). Proponents argue that the electricity generated is crucial to the development of basin countries. This fact is generally not disputed but opponents argue that the environmental and human costs have been unnecessarily high due to improper planning and management, and that the costs and benefits have not accrued equally to all stakeholders (Morrissey 2006).

Figure 2.14.4: Cahora Bassa dam and reservoir





Cahora Bassa Dam in western Mozambique

### Cahora Bassa Dam

Cahora Bassa Dam was constructed in 1974 under the control of the Zambezi Valley Planning Authority. It was intended to provide hydropower generation, navigation, irrigation and water for mining and industry. Cahora Bassa's closure, along with other upstream impoundments, further regularized the flow. The dam has primarily been managed to produce hydroelectric power, most of it for sale to South Africa and to a lesser extent to Zimbabwe. This hydropower will likely to be reduced to below optimal levels should all the dams along the Zambezi be managed to mimic natural flooding to benefit affected ecosystems (Beilfuss 2006) (Figure 2.14.4).

The dam's human and environmental costs include a decline in coastal fisheries, loss of mangroves along the coast, changes in wetland

vegetation, increased disease carrying insects and invasive plants. Project evaluations prior to the dam's closing anticipated these impacts and recommendations that would have minimized these costs were not followed in the early days of the dam's operation. Recent studies recommended flow management to restore some of the river's pre-impoundment functions by simulating natural flow variations (Davies 2000, Beilfuss 2006).

Further dams are planned, including the Mphanda Nkuwa Dam roughly 113 km downstream of Cahora Bassa. Its hydroelectric facility will have an installed capacity of 1 300 MW (UTIP n.d.). This electricity is intended to facilitate development in Mozambique but initially the bulk of it will be sold to South Africa (IR 2006). Several NGOs and researchers have raised concerns over the project's environmental and human costs (Beilfuss 2006, IR 2006).



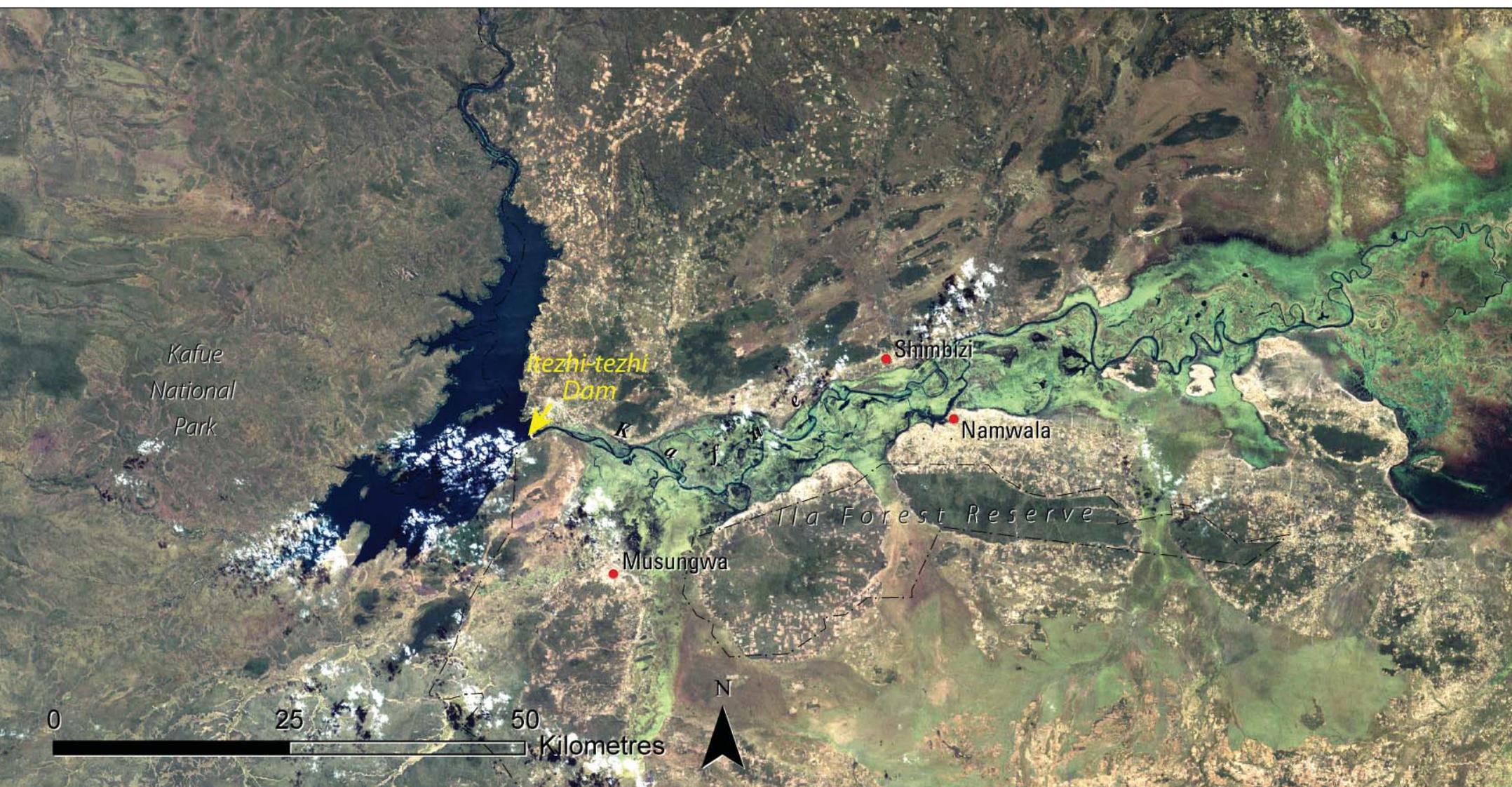
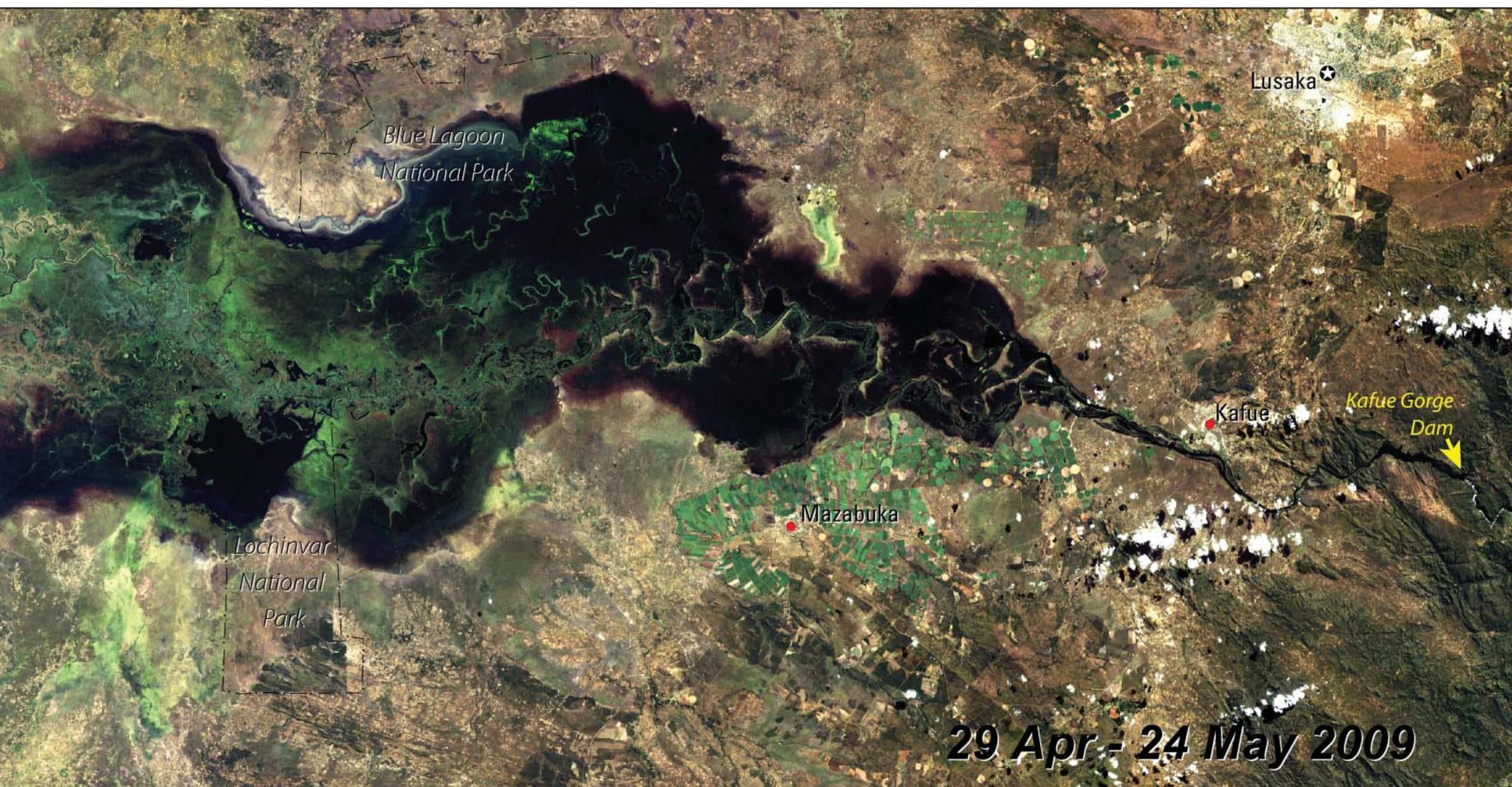


Figure 2.14.5: Kafue Flats before and after water release

### Kafue Flats

The Kafue River, one of the Zambezi's main tributaries, crosses a broad floodplain roughly 255 km long as it passes between the Itezhi-tezhi dam and the Kafue Gorge Dam. Before the Itezhi-tezhi Dam was built on the river in 1978, flooding began in December and would cover much of the plain well

into the dry season. Although the dam was built to allow the release of sufficient water to mimic natural seasonal flooding, it is not clear to what extent this was done in the past. This floodplain provides important habitat for rare and endemic species, including the Kafue lechwe and wattled crane, and supports local livelihoods, especially cattle-raising and fishing (Schelle and Pittock 2005). Limited



seasonal flooding following the dam's construction has been linked to a decline in fish production and reduced numbers of Kafue lechwe. The number of lechwe fell from around 90 000 before the dam was built to around 37 000 in 1998 (CEH 2001).

In 2004, a partnership between World Wildlife Fund, the Zambian Ministry of Energy and Water Development, and the Zambian Electricity Supply

Company put new rules in place so that water releases from the dam mimic natural flooding patterns (WWF 2007).

The 2008 satellite image in Figure 2.14.5 is from the dry season when floodwaters have generally receded. The 2009 image from seven months later shows the extent of the annual floods during the wet season, aided by managed releases.

# Transboundary Aquifers

Just as there are internationally shared river basins, there are also internationally shared, or transboundary, water resources and aquifers hidden underground. Some of the world's transboundary aquifers contain huge freshwater resources, enough to provide safe and good-quality drinking water for the needs of all humanity for decades (UNESCO 2001) (Figure 2.15.1). Generally, aquifer systems contain excellent quality water, due in part to their relative isolation from surface impacts. The hidden nature of transboundary groundwater and lack of legal frameworks to manage them, however, also

invite misunderstanding by many policy makers. Not surprisingly therefore, transboundary aquifer management is still in its infancy, since groundwaters are difficult to evaluate and there is a lack of institutional will and finances to collect the necessary information. Although there are fairly reliable, detailed estimates of the water resources in rivers shared by two or more countries, no equivalent estimates exist for transboundary aquifers (Salman 1999).

In Africa, groundwater is an important source of freshwater and it is essential to supplement the surface water resources in a region that is increasingly

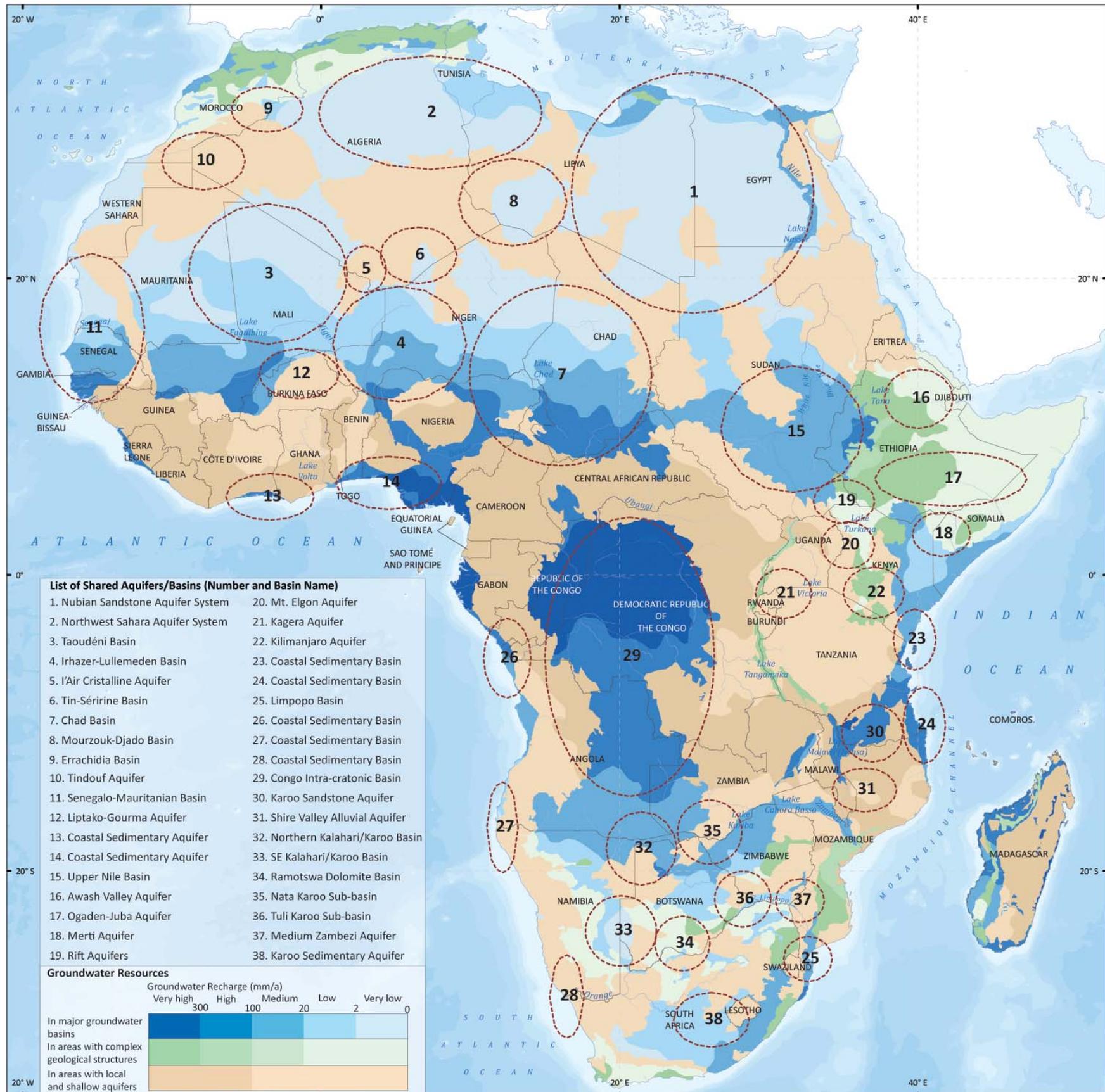


affected by recurrent drought. Africa is endowed with large and often under-utilized aquifer resources, predominantly in the large shared subregional sedimentary systems of the Sahara and Central and Southern Africa. There are also significant shared coastal aquifer resources that supply the large urban populations concentrated in rapidly growing coastal areas (Figure 2.15.2).

Large shared aquifer resources often represent the only source of drought security and life sustenance for large populations in semi-arid areas. While the linkages between surface water and groundwater are critical to aquifer recharge, the watersheds in many aquifer recharge zones are threatened by accelerated land degradation and



Figure 2.15.1: Transboundary aquifers (Source: adapted from UNESCO-IHP/ISARM 2004)





# Nubian Sandstone Aquifer

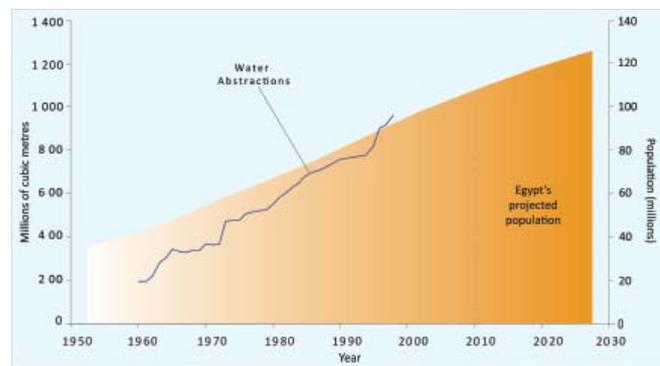


The Nubian Sandstone Aquifer System underlies virtually all of Egypt, much of eastern Libya, and significant areas of northern Chad and northern Sudan (CEDARE 2001). It can be broadly described as two distinct aquifer systems vertically separated by layers of lower permeability that allow some upward leakage (Aiker 2008). The deeper Nubian Sandstone Aquifer System is older and extends to the entire area while the Post Nubian Aquifer System lies above that in more recent geological formations and covers roughly the northern half of the larger system (CEDARE 2001).

People have been extracting groundwater to a limited degree for thousands of years in the North African desert (Shahin 1987). Historical rates of use, however, are relatively insignificant compared to the current rate of abstraction in the Nubian Sandstone Aquifer System, which has increased by roughly 500 per cent since the early 1960s when large-scale development began (Bakbakhi 2006) (Figure 2.16.2). Models of the aquifer's water budget show that the current scale of groundwater use and the increased rate

Figure 2.16.1: Nubian Sandstone Aquifer





**Figure 2.16.2: Water abstraction by population (Source: CEDARE 2001)**

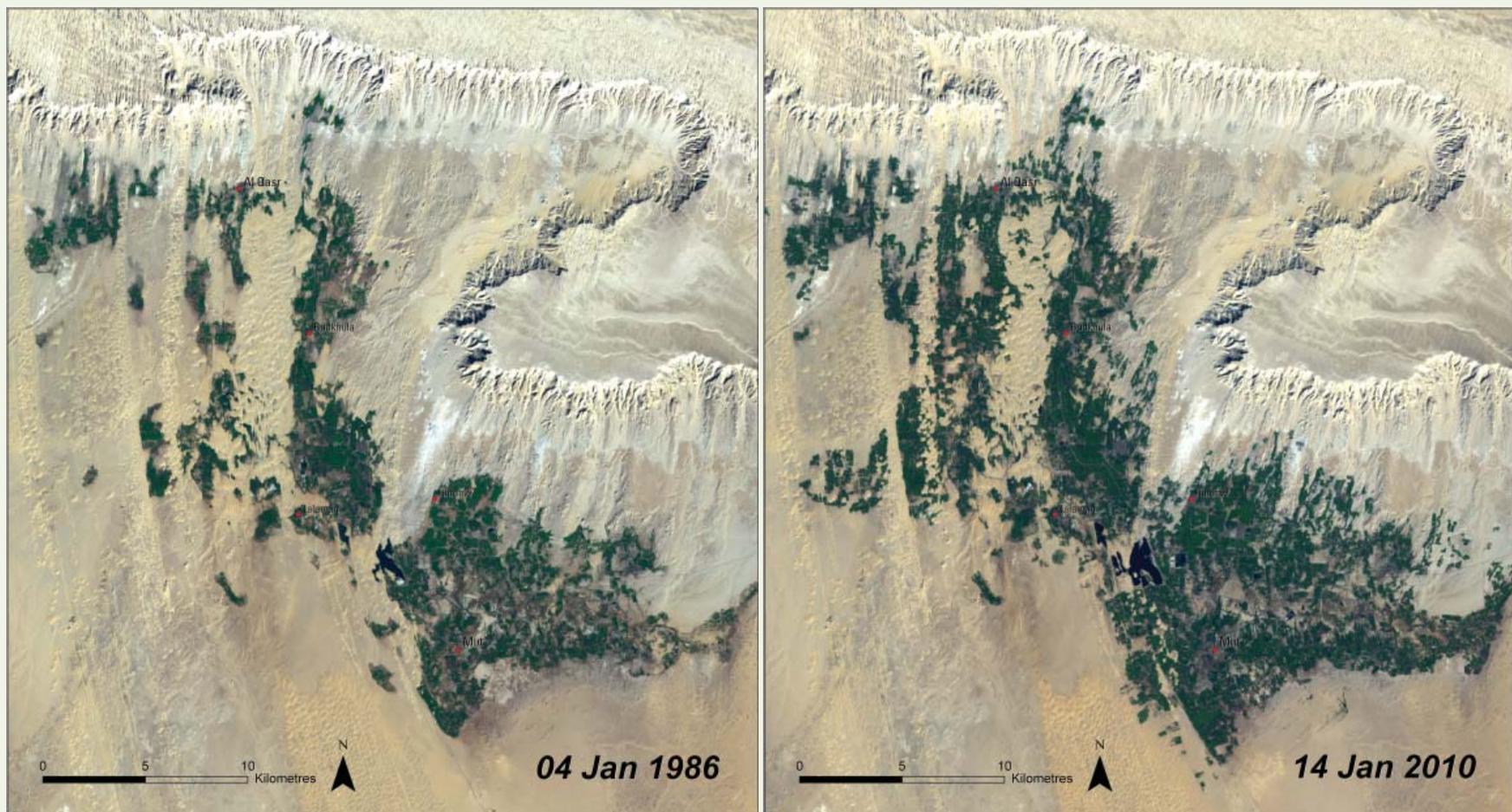
of groundwater decline will significantly exceed historical rates (Ebraheem and others 2003).

While it is clear that the aquifer system holds an enormous reserve of water, estimates vary considerably as to the amount—from as little as 15 000 km<sup>3</sup> (Alker 2008) to 135 000 km<sup>3</sup> (Gossel and others 2004), to as much as 457 570 km<sup>3</sup> (Bakhabkhi 2006). It is generally believed that the aquifer's water dates from wetter climates in the past (5 000–10 000 and 20 000–25 000 years BP) and that no significant recharge is taking place under current climate

conditions (Gossel and others 2004, CEDARE 2001, Ebraheem and others 2003). Experts generally accept that the system has not been in equilibrium for thousands of years and that groundwater levels were already declining well before artificial extraction began (Heinl and Brinkman 1989, Gossel and others 2004). Thus, any water withdrawal from the aquifer under the current climate would be considered “water mining,” or a rate that exceeds recharge.

### Precipitation

Arid and hyper-arid climate conditions in most of the region dramatically magnify the aquifer's importance. Almost all of the water used by people living above the aquifer comes either from groundwater abstraction or diversion from the Nile. The average annual mean rainfall is less than 50 mm and on average vast areas over the aquifer system receive no measurable precipitation. The wettest area at the northernmost tip of Libya receives around 425 mm of rain. Northern Darfur in Sudan is the wettest area to the south but sees only an average of around 200 mm each year (Figure 2.16.4).

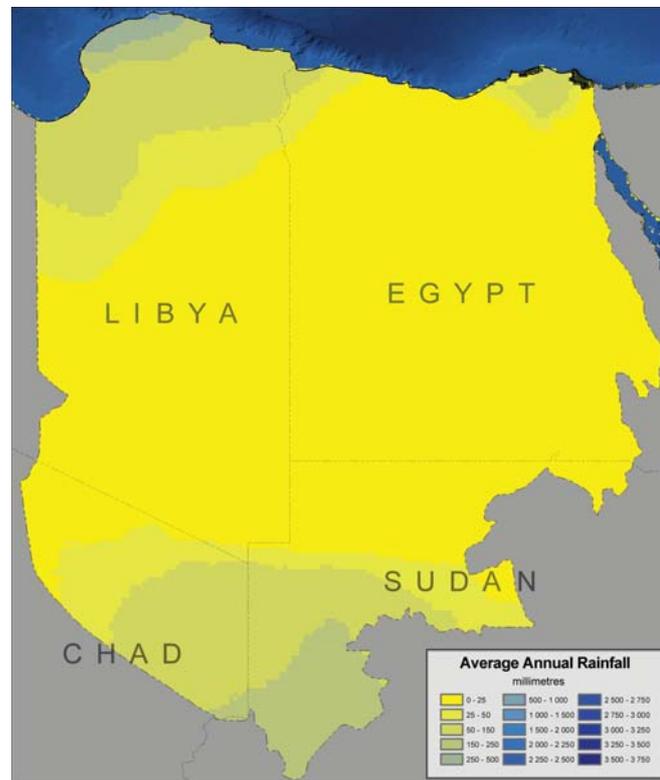


**Figure 2.16.3: Dakhla Oasis, 1986-2010**

### Desert Oasis Development – Dakhla Oasis

Dakhla Oasis lies 300 km west of the Nile and is surrounded by the driest of desert landscapes. Its location over the southern edge of the Post Nubian Aquifer, however, provides access to both shallow and deep wells within the Nubian Sandstone Aquifer System. While it is currently home to fewer than 100 000 people, archeologists believe that the Dakhla Oasis has been continuously settled for around 8 000 years (Dakhleh Project n.d.). Water extraction from the deeper Nubian Sandstone Aquifer at the Oasis has grown ten-fold

since 1960 (CEDARE 2001). The related growth in agriculture can be seen in the pair of satellite images that span just a few of those years—1986 to 2010 (Figure 2.16.3). Faced with increasingly crowded populations along the Nile, the Egyptian government has been further developing settlement and agriculture in the Western Desert's oasis. Some studies suggest that the planned rate of abstractions for these areas is unsustainable, however, because it will lead to local depressions in the water table making water more and more expensive to access (Ebraheem and others 2003).



**Figure 2.16.4: Nubian Sandstone Aquifer System average annual rainfall**



**Figure 2.16.5: Nubian Sandstone Aquifer System population density**

### Population

Egypt's population of over 80 million people makes up almost 98 per cent of the entire population living over the Nubian Sandstone Aquifer System (NSAS) (Figure 2.16.5). Egypt's population has doubled since 1975 and is projected to grow to over 129 million by 2050 (UNESA 2008). This situation alone would mean that by the second half of this century, five times as many people will be sharing the same water resources as in 1960. Because of the Nile Valley's intense concentration of people, the Egyptian Government has been seeking ways to attract people to areas away from the river including regions of

well-field development or expansion at East Oweinat, Bahariya, Farafra, and Dakhla, which will rely on water from the Nubian Sandstone Aquifer System (Ebraheem and others 2003).

In addition to the increasing number of users, however, less water will be available to share as levels decline. Modeling of the aquifer system's water balance shows that present extraction rates are responsible for measurable changes in water storage (Ebraheem and others 2003). Furthermore, where heavy pumping occurs, the areas develop depressed cones in the groundwater level, which could make it prohibitively expensive to pump for irrigation in the future (Ebraheem and others 2003).





Lake Yoa in the Ounianga Serir Basin lies in the hyper-arid Sahara Desert but is replenished with water from the Nubian Sandstone Aquifer System

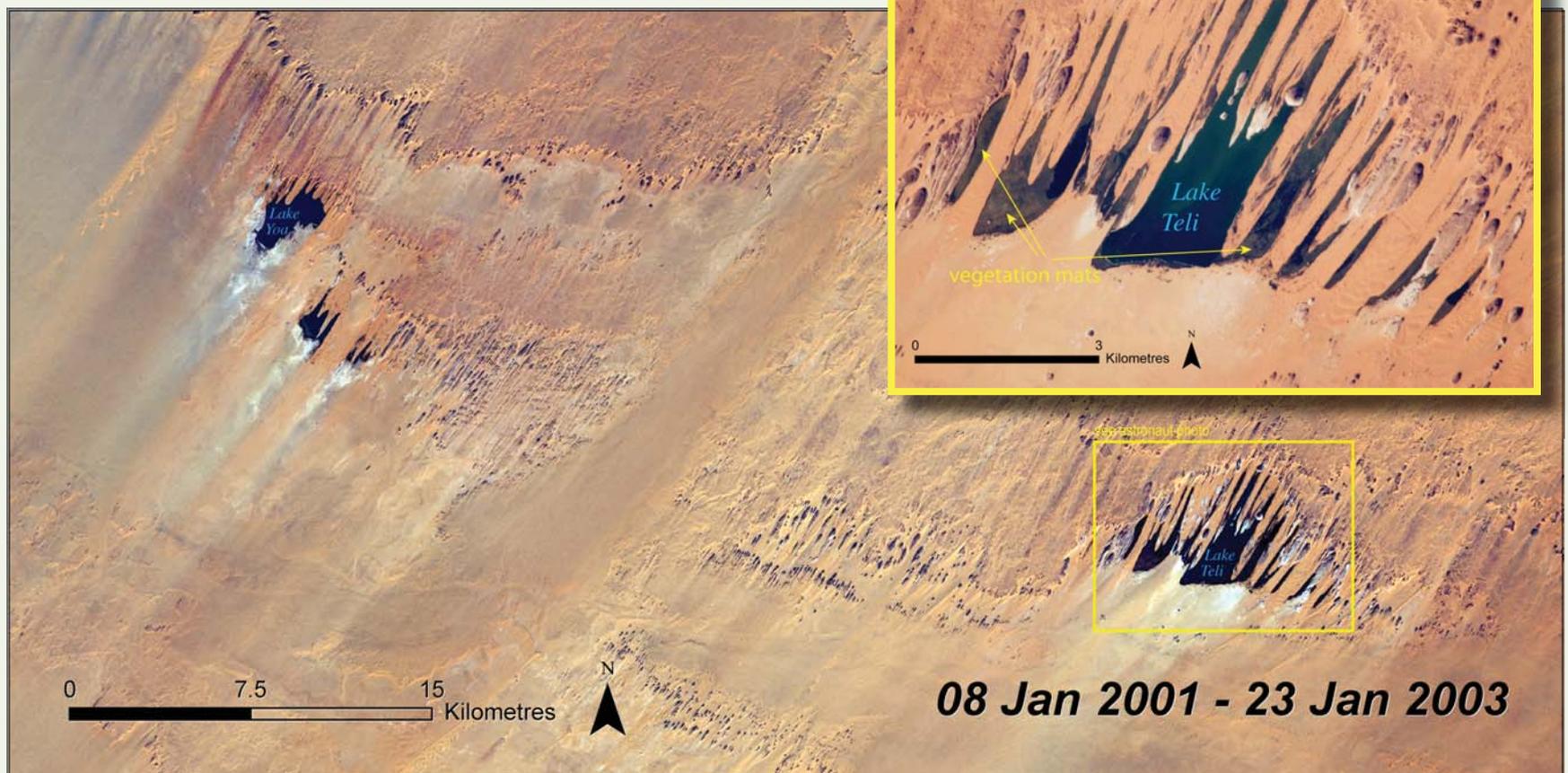
### Ounianga Basin Lakes in the Sahara

The Ounianga Depression lies in northeastern Chad between the Tibesti and Ennedi mountains, in the middle of the Sahara Desert. The area receives an average of only a few millimetres of rain annually but has an evaporation potential of over 6 000 mm—among the highest in the world (Kröpelin 2009). Nevertheless, a series of lakes survive in the desert here, fed by a continuous supply of water from the Nubian Sandstone Aquifer System (Eggermont and others 2008, Grenier and others 2009, Kröpelin and others 2008). Extreme evaporation in this type of hyper-arid environment typically concentrates dissolved salts making lakes very saline, and the two largest lakes are Lake Yoa and

Lake Teli. Several of the smaller lakes surrounding Lake Teli, however, have freshwater due to a unique combination of factors including vegetative mats that reduce evaporation and a pattern of flow that draws freshwater through smaller lakes on its way to the large saline Lake Teli (Kröpelin 2007). The vegetation mats can be seen covering much of the surface of the smaller lakes (Figure 2.16.6).

In spite of the extreme conditions people still live in the Ounianga Serir basin. A village, Ounianga Kebir, is located on the west shore of Lake Yoa (western most lake in satellite image). Salt extraction, date-palm cultivation, and grazing cattle are sources of livelihood (Hughes and Hughes 1992).

Figure 2.16.6: Ounianga Basin Lakes, 2001-2003





### The Great Man-Made River Project

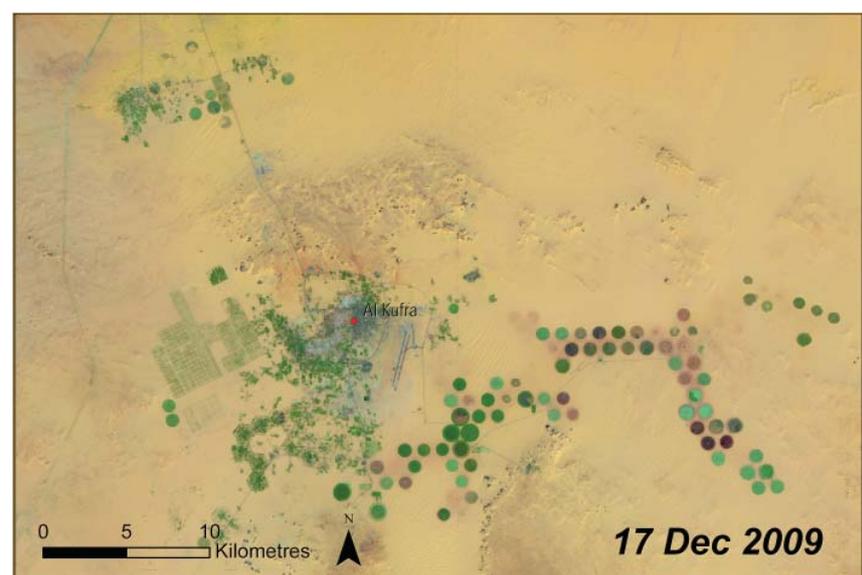
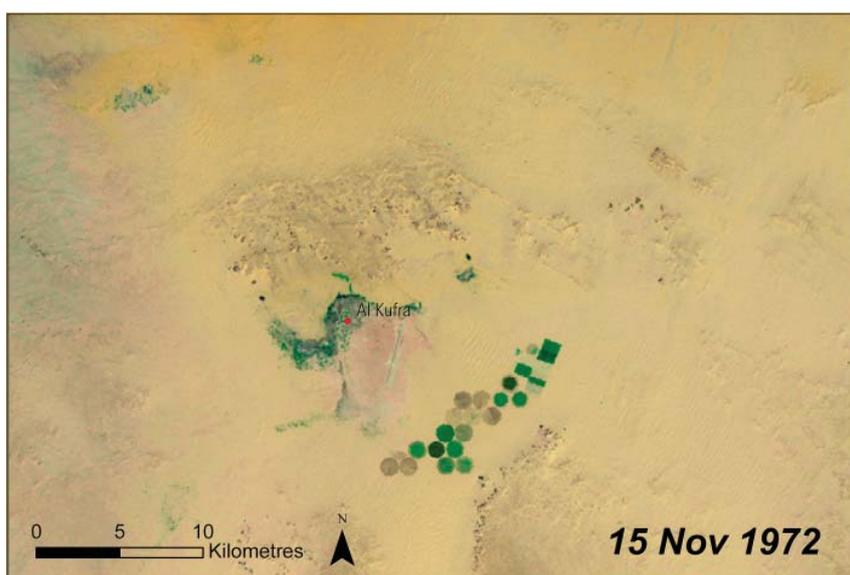
Libya is one of the African countries with the least amount of renewable water. It relies on groundwater to meet 95 per cent of its water requirements. The water is primarily “fossil water” from non-recharging aquifers such as the Nubian Sandstone Aquifer System, the North-Western Aquifer System and the Murzuq Basin Aquifer System (Alker 2008). While Libya has some aquifers in the north with limited recharge, salt-water intrusion due to over-pumping and growing demands have made it necessary for Libya to look elsewhere to meet its water needs (Ghazali and Abounahia 2005). In the 1960s, the discovery of water in deep aquifers located under Libya’s southern desert inspired an enormous water-transfer scheme—the Great Man-Made River Project.

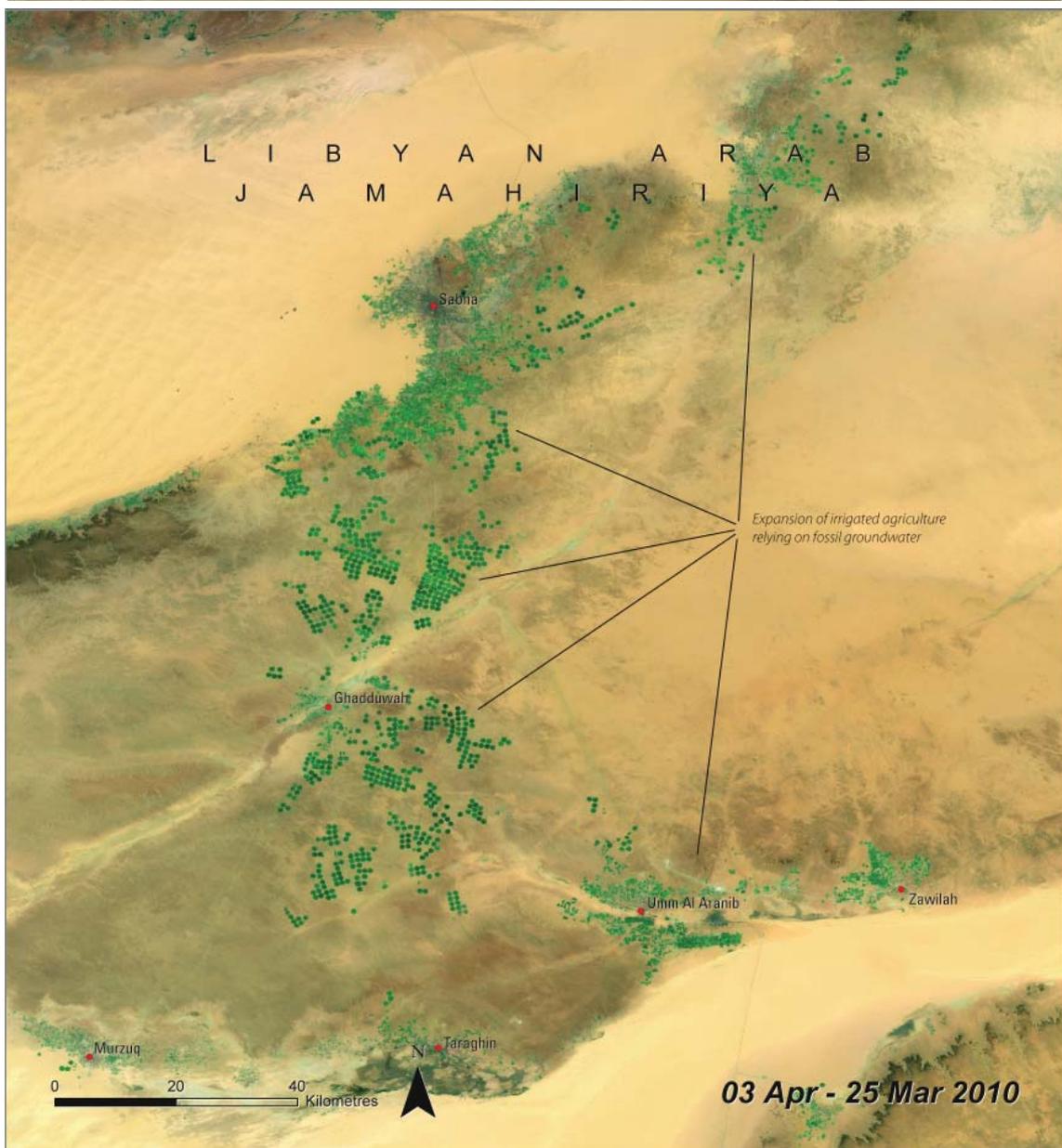
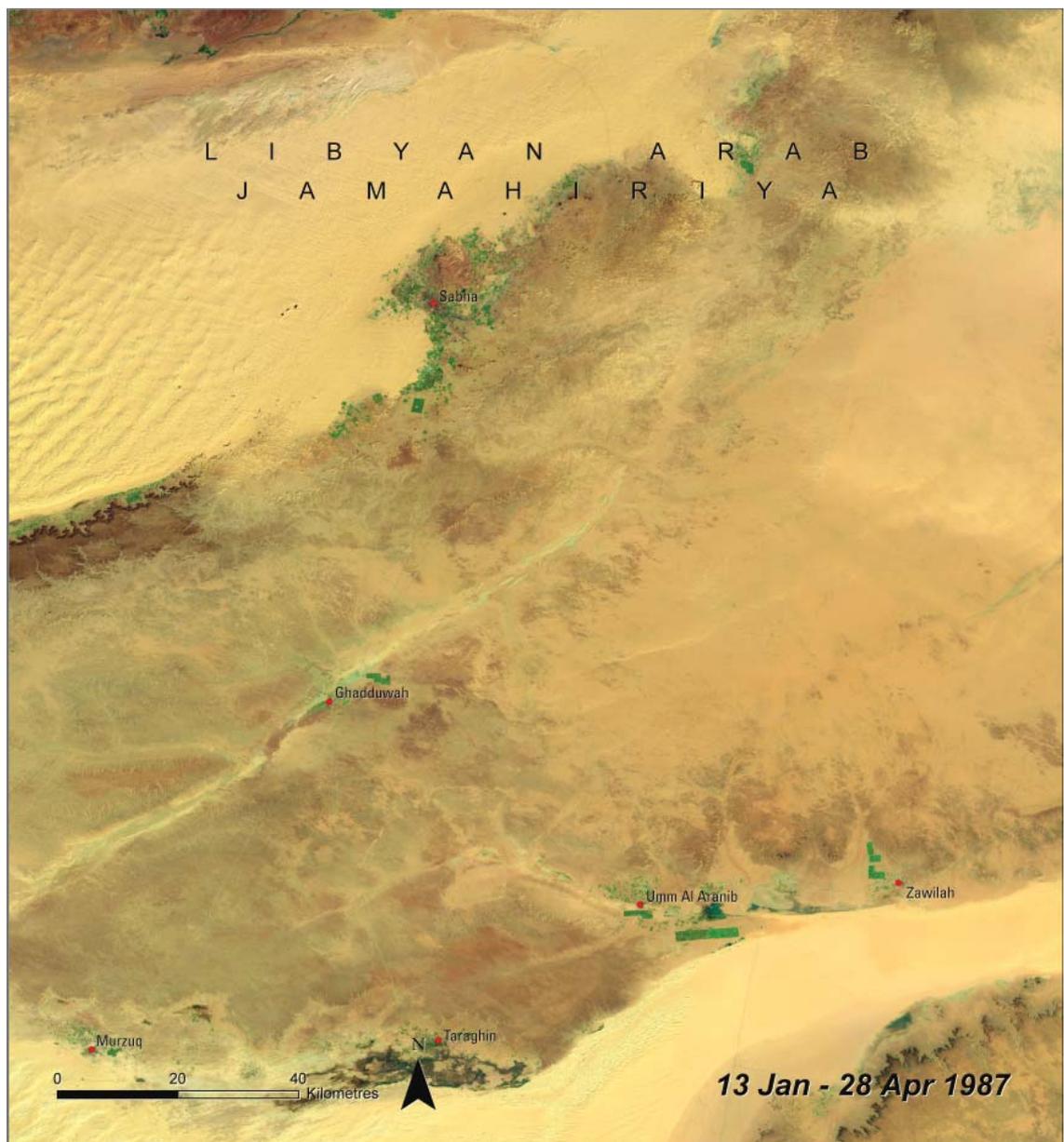
Work on the Great Man-Made River Project in Libya began roughly 30 years ago. The project brings water from well fields in the Sahara to Libya’s population, which is generally concentrated in the northern plains along the Mediterranean Coast. The



**Figure 2.16.7:** The East and North East Jabal Hasaouna well fields supply water for irrigation on the Murzuq Basin and to Tripoli and the Jeffara Plain in the north

**Figure 2.16.8:** The expansion of center-pivot irrigation (green and brown circles) between 1972 and 2009 is supplied by water from wells drawing from the Nubian Sandstone Aquifer System, which are a part of the Great Man-Made River Project





water is for industry, domestic use and to support irrigated farms that feed Libya's growing population. The system is among the largest civil engineering projects in the world.

The majority of the system's water comes from Libya's two largest groundwater resources—the Murzuq and Kufra groundwater basins (Alghariani 2007). Located in Libya's southern desert, they hold over two-thirds of Libya's groundwater reserves (Alghariani 2007). Neither aquifer system receives significant recharge; consequently any withdrawal of water reduces the total reserves. While the total volume of water in the two aquifers is enormous, drawdown of the water levels under heavy usage could eventually make extracting water prohibitively expensive (Shaki and Adeloje 2006, Alghariani 2003). The July 2010 image (Figure 2.16.7, previous page) shows some of the wells of the East and North East Jabal Hasaouna well fields, which abstract around two million m<sup>3</sup> of water daily from the Murzuq Basin Aquifer (Abdelrhem and others 2008).

The satellite image pairs (Figure 2.16.9) show the large increase in centre pivot irrigation at two locations—one drawing from the Kufra Basin in the southeast and the other from the Murzuq Basin in the southwest. The majority of Libya's groundwater, as much as 80 per cent (Alghariani 2003), is used for agriculture including wheat, alfalfa, vegetables and fruits. Water and agricultural demands are driven by Libya's population, which was growing at just over two per cent per year in 2008, down from five per cent per year in the early eighties (World Bank 2010). Since the project's initiation in 1983 the cost of alternative sources of water, particularly by desalinization, has become competitive with water delivered by the Great Man-Made River transfer scheme (Alghariani 2003) and will likely become less expensive in the foreseeable future.

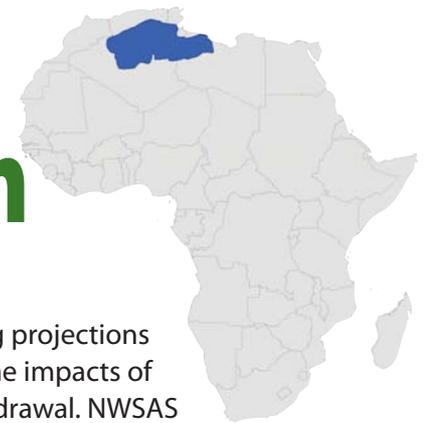
The project is being built in several stages. Phase One provides two million cubic metres per day from wells at Sarir and Tazerbo to the Northern Cities of Benghazi and Sirte. The second phase delivers water to the Jeffara Plain and to Tripoli. The third phase of the project has begun construction, although some parts of that phase have been cancelled (WaterTechnologyNet n.d.).

Figure 2.16.9: Expansion of irrigated agriculture relying on fossil groundwater



Figure 2.17.1: North-Western Sahara Aquifer System

# North-Western Sahara Aquifer System



The North-Western Sahara Aquifer System (NWSAS) covers a total area of over one million km<sup>2</sup>: 700 000 km<sup>2</sup> in Algeria, 80 000 km<sup>2</sup> in Tunisia and 250 000 km<sup>2</sup> in Libya (Figure 2.17.1). It contains sedimentary deposits that have two main levels of aquifers, the Intercalary Continental (IC) and the Terminal Complex (TC). The three NWSAS countries have embraced an approach of joint management. This approach is based on an in-depth knowledge of

the aquifer, including projections and simulations of the impacts of intensive water withdrawal. NWSAS is crucial to development in the north-western part of the Sahara desert, especially to secure food for a growing population close to, and even far beyond its borders, and to meet the demands of agriculture, industry, and construction.



# Iullemeden-Irhazer Groundwater Basin



The Iullemeden sedimentary groundwater basin (IAS) is located in Mali, Niger and Nigeria with minor, non-connected sections in Algeria and Benin. The aquifer system, which covers an area of 525 000 km<sup>2</sup> with 31 000 km<sup>2</sup> in Mali, 434 000 km<sup>2</sup> in Niger and 60 000 km<sup>2</sup> in Nigeria, represents one of West Africa's major freshwater reservoirs and is linked to many humid areas and ecosystems (Figure 2.18.1).

With high demographic growth (from six million in 1970 to about 15 million in 2000 and probably 30 million by 2025) and the impacts of climatic change and variability, including regional drought over the last several decades, the Iullemeden aquifer system increasingly suffers from environmental stress. Annual water withdrawals of about 50 million m<sup>3</sup> in 1970 increased to about 170 million m<sup>3</sup> in 2004 and the IAS is changing from a strategic regional resource to an increasingly well-used aquifer system. Total abstractions now exceed the annual aquifer recharge

and there are visible impacts of declining water tables, loss of artesian pressure and aquifer pollution in local hotspots and border areas. The IAS interacts with the regional Niger River through seepage inflows that support the river's water resources during periods of low flow and extended drought.

A number of environmental threats to the aquifer and the related ecosystems have been identified including land-use change in recharge areas and humid zones of the IAS; climatic change; over-extraction; human-induced water pollution, and land salinization. To address these threats and risks, joint mechanisms and cooperative frameworks have been established. Scientific uncertainty about the aquifer system and the impacts of climate change, however, constrain the scope for managing transboundary risk and conflict in the IAS.

**Figure 2.18.1: Iullemeden-Irhazer Basin**



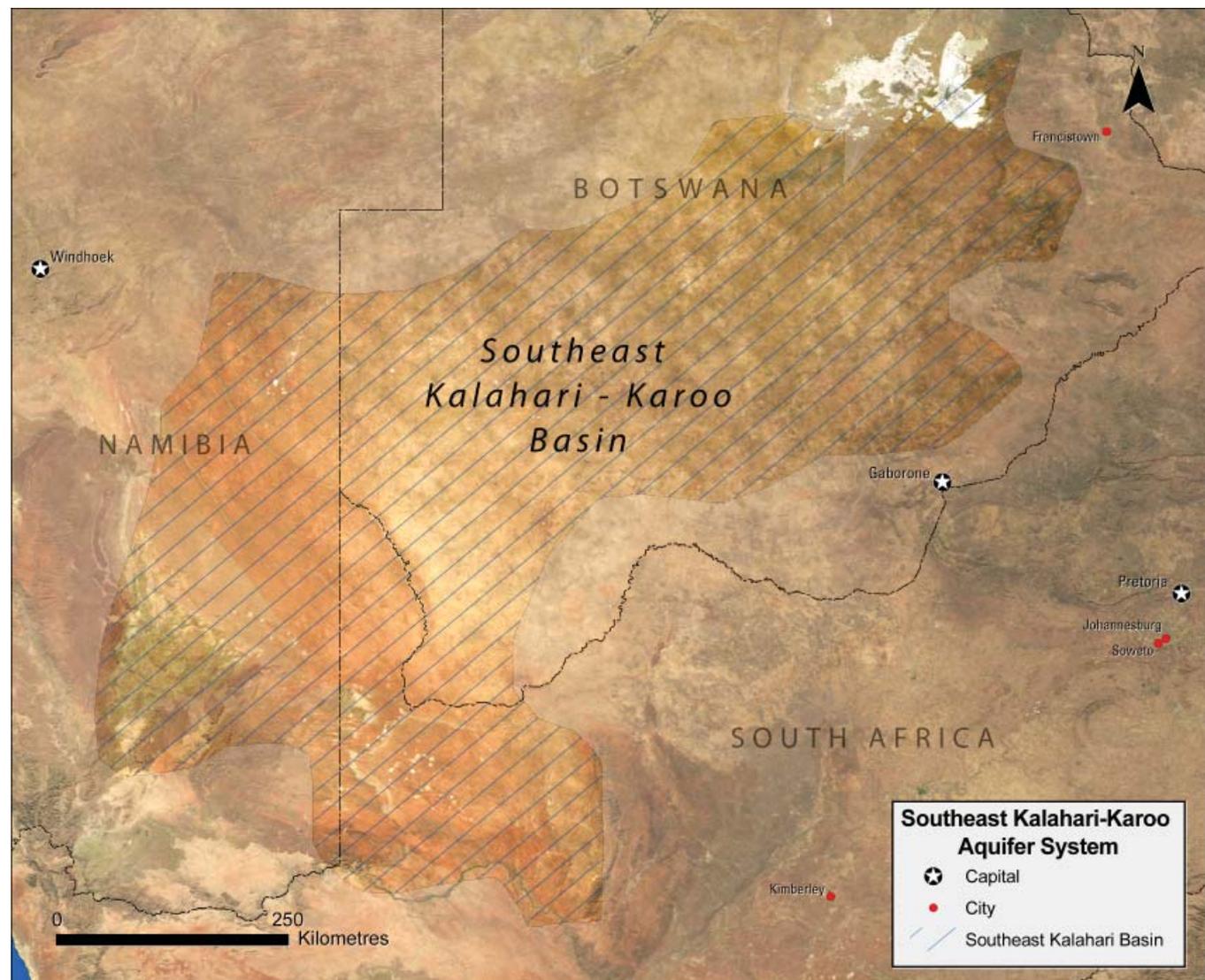


Figure 2.19.1: Southeast Kalahari Karoo Aquifer

# Southeast Kalahari Karoo Aquifer



The Southeast Kalahari Karoo aquifer is shared by Namibia, Botswana, and South Africa, although it is predominantly used in Namibia where most recharge probably occurs (Figure 2.19.1). There is a comparatively good understanding of the aquifer's geology and hydrogeology in Namibia. Water occurs in the Auob and Nossob sandstones of the Ecca Group (lower Karoo Sequence), as well as in the overlying Kalahari. The dip of the formations is slightly towards the southeast and in general the water quality deteriorates also in that direction (by about three degrees).

Population on the Namibian side is generally sparse; water usage is therefore primarily for irrigation and stock farming. Although the system is large, because of present uncertainty about recharge it is not known if it can sustain large irrigation schemes, so the appropriate balance between irrigation and sustainability is currently unresolved.

The Southeast Kalahari Artesian aquifer is bordered by the south-west part of Botswana, the South

African Kalahari National Game Park, and the Gordonia District. In Gordonia, water quality of the Karoo aquifers appears to be very poor, as in the so-called Salt block in the southeastern part of the Artesian basin in Namibia. At present, water is used in Namibia for stock watering and increasingly for irrigation purposes. The system also supplies five smaller towns with water. By far the largest portion of the aquifer falls within Namibia, which is expected to have the largest demand from the system and where need is expected to rise in the future.

### Significant issues concerning the shared aquifer

The major issue at this stage is for all three countries to obtain a proper understanding of the aquifer for joint management of the resource. The countries can then work out a legal framework for a common abstraction policy.

## Coastal Aquifers

As with any groundwater resource, the rate of abstraction in coastal aquifers cannot exceed the rate of recharge indefinitely without exhausting supply. About 2.7 per cent of Africa's population lives within 100 km of the coast (UNEP 2008). While this degree of concentration is lower than on the other continents (Hinrichsen 1995), Africa's coastal population is growing rapidly (UNEP 2008). In many cases, this rising pressure on coastal groundwater resources has exceeded sustainable levels (Steyl and others 2010). In addition, excessive abstraction from coastal aquifers can also lead to saltwater intrusion as seawater replaces the extracted water.

Twelve of Africa's coastal groundwater aquifers are shared by two or more of the continent's 32 coastal countries. The shared hydrogeology in these cases makes management a joint concern of the populations and governments of all countries involved.

Across North Africa, dependence on groundwater is magnified by the arid environment and the lack of alternative freshwater sources. Nearly half of all groundwater withdrawn in Africa comes from aquifers in this region. Tunisia obtains 95

per cent of its freshwater supply from groundwater. The arid environment also means that recharge is minimal outside of the coastal zone where some rainfall occurs and away from rivers that provide some recharge to shallow aquifers. Consequently, several North African locations are experiencing serious seawater intrusion including the Nile Delta, Tunisia, Libya, Algeria, and Morocco. Several factors have contributed to an alarming drop in water tables in the Maghreb including drought, urbanization, and abstraction for agriculture (Steyl and others 2010).

The Siwa Oasis in Egypt and the Jaghbub Oasis in Libya are located at the margins of the saltwater-freshwater interface in the Nubian Sandstone Aquifer System (Figure 2.20.1). Modeling of the aquifer's response to current water abstraction at Siwa shows a slight cone of depression in the surrounding water table's surface (Elbadawy 2007). The original plans for the Great Man-Made River Project in Libya included a well-field south of Jaghbub and south of the freshwater-saltwater interface. Research that modeled the impact this would have on the seawater intrusion in the area has raised concern and further research has been recommended before proceeding with this part of the project (Schlumberger Water Services 2007).

**Figure 2.20.1: Abstraction of freshwater from coastal aquifers can lead to saltwater intrusion as sea water replaces the water that is withdrawn. A thorough understanding of the underlying hydrogeology is needed to manage this risk**

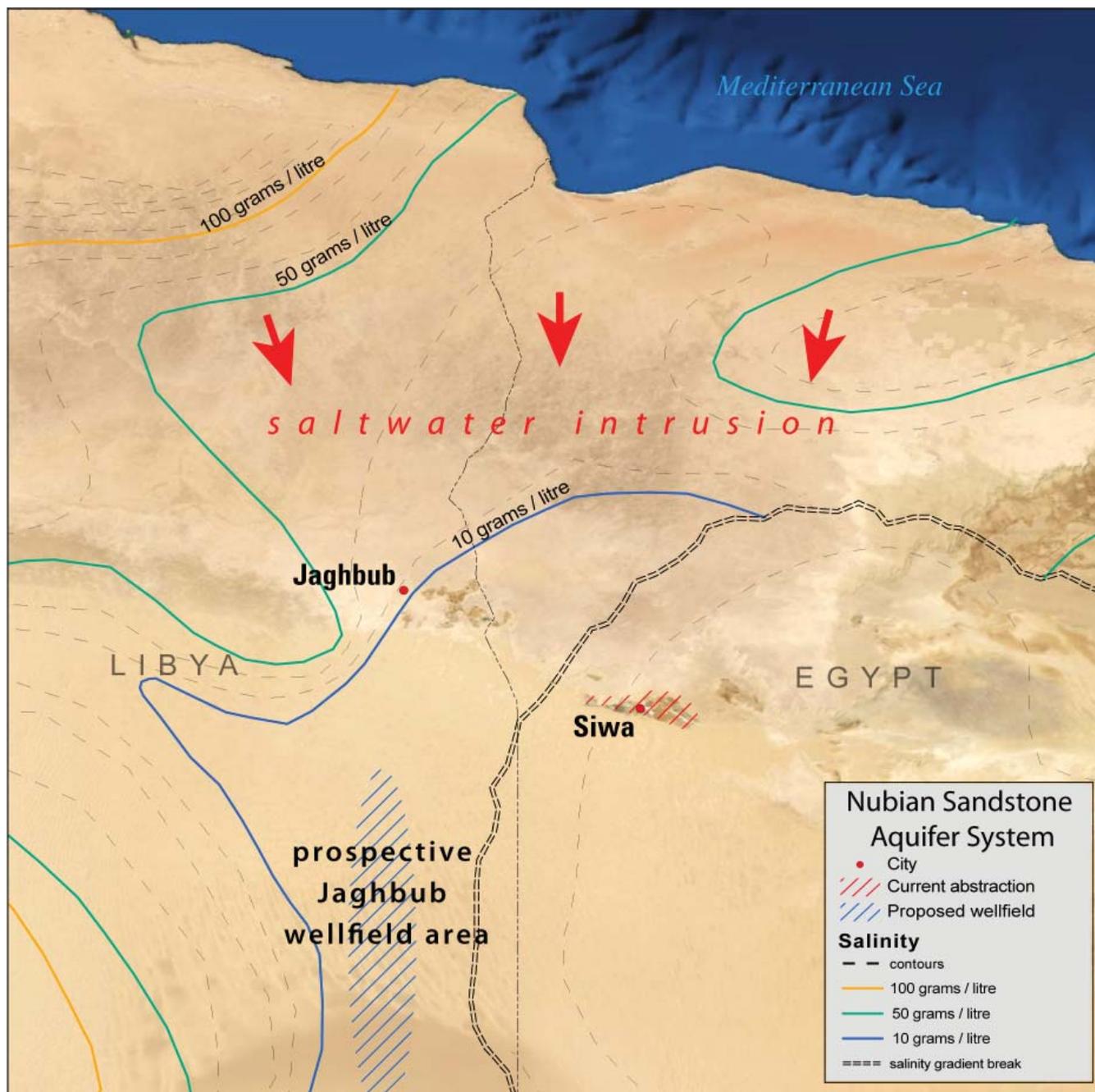




Figure 2.21.1: Map of Tano Groundwater Basin/Abidjan Aquifer

# Tano Basin Abidjan Aquifer



Western Africa's aquifer systems are generally complex with a variety of hydrogeological settings and varying levels of utilization. Coastal aquifers at several locations in Western Africa have been found to be deteriorating due to over-exploitation, and in some cases due to the infiltration of domestic, agricultural, and industrial pollutants.

Sedimentary aquifers straddling the border between Côte d'Ivoire and Ghana are the principal water source for several urban areas along the Gulf of Guinea including Abidjan, Côte d'Ivoire—a city of around four million people (Oga and others 2008). There are two aquifers in a regional unconfined system: the Quaternary Aquifer along the coast and the more important Continental Terminal Aquifer just

inland of the Quaternary (Oga and others 2008).

The aquifers are under intense pressure from domestic, industrial, and agricultural use in this area where population growth is around two per cent annually. In some places water quality has deteriorated as over-abstraction has led to sea-water intrusion, although salinity in the aquifers remains relatively minor (Oga and others 2008). There are also some areas where domestic waste disposal and agricultural pollution have degraded water quality creating high concentrations of nitrates (Oga and others 2008). There is currently no transboundary management of this important groundwater resource.



# References

## Transboundary Surface Water Basins

SEDAC. (2010). Gridded Population of the World: Future Estimates. Socioeconomic Data and Applications Center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT. <http://sedac.ciesin.columbia.edu/gpw> (Last accessed on August 10, 2010).

UNU. (2006). International Rivers and Lake Basin Management, United Nations University. <http://www.unu.edu/env/water/transboundary-water.html> (Last accessed on September 10, 2010).

UNEP. (2006a). Global Deserts Outlook. United Nations Environment Programme, Nairobi, Kenya.

UNEP. (2006b). Africa's Lakes: Atlas of Our Changing Environment. United Nations Environment Programme, Nairobi, Kenya.

### Congo River Basin

Béné, C., Steel, E., Luadia, B., Gordon, A. (2009). Fish as the "bank in the water" – Evidence from chronic-poor communities in Congo. *Food Policy*, 34:108-118.

Counter Balance. (2009). Conrad's Nightmare, The World's Biggest Dam and Development's Heart of Darkness. [http://www.counterbalance-eib.org/component/option,com\\_datagallery/Itemid,98/func,detail/id,128/](http://www.counterbalance-eib.org/component/option,com_datagallery/Itemid,98/func,detail/id,128/) (Last Accessed on February 25, 2010).

Dai, A. and Trenberth. (2002). Estimates of Freshwater Discharge from Continents: Latitudinal and Seasonal Variations. *Journal of Hydrometeorology*, 3:660-687.

Davies, B., Beilfuss, R., Thoms, M. (2000). Cahora Bassa retrospective, 1974-1997: effects of flow regulation on the Lower Zambezi River. *Verh. Internat. Verein. Limnol.* 27:1-9.

DeGeorges, A. and Reilly, B. (2006). Dams and Large Scale Irrigation on the Senegal River. Impacts on Man and the Environment. Case Study for 2006 Human Development Report. UNDP.

EIA. (2002). Inga Hydroelectric Facility. Energy Information Administration. Food and Agriculture Organization of the United Nations. <http://www.eia.doe.gov/emeu/cabs/inga.html> (Last Accessed on February 26, 2010).

FAO. (1997). Irrigation potential in Africa: A basin approach – FAO Land and Water Bulletin – 4. Food and Agriculture Organization of the United Nations. <http://www.fao.org/docrep/w4347e/w4347e00.htm> (Last Accessed on February 25, 2010).

FAO. (2001). Information on fisheries management in the Democratic Republic of the Congo. Food and Agriculture Organization of the United Nations. <http://www.fao.org/fi/oldsite/FCP/en/COD/BODY.HTM> (Last Accessed on February 25, 2010).

FAO. (2002). FAO Rice Information. Democratic Republic of the Congo. Food and Agriculture Organization of the United Nations. <http://www.fao.org/DOCREP/005/Y4347E/Y4347E00.HTM> (Last Accessed on February 26, 2010).

FAO. (n.d.). Aquastat Country Profile - République démocratique du Congo. Food and Agriculture Organization of the United Nations. [http://www.fao.org/nr/water/aquastat/countries/congo\\_dem\\_r/indexfra.stm](http://www.fao.org/nr/water/aquastat/countries/congo_dem_r/indexfra.stm) (Last Accessed on February 26, 2010).

IR. (n.d.a.). "Inga 1 and Inga 2 dams". *International Rivers*. <http://www.internationalrivers.org/en/node/2877> (Last Accessed on February 26, 2010).

IR. (n.d.a.). "Inga 3". *International Rivers*. <http://www.internationalrivers.org/en/africa/grand-inga-dam-dr-congo/inga-3> (Last Accessed on February 26, 2010).

IR (n.d.c.). Grand Inga, Grand Illusions. *World Rivers Review*. 20(2):6-7. <http://www.internationalrivers.org/files/WRR/V20.N2.pdf> (Last Accessed on September 10, 2010).

IR. (2008). "Pimping Inga". *International Rivers*. <http://www.internationalrivers.org/blog/terri-hathaway/pimping-inga-0> (Last Accessed on August 10, 2010).

Kirongozi, H. (2008). Sustaining Congo River and its Communities: Congolese Mining Industry to Grow Green. *International River Symposium 2008* paper presentation. <http://www.riversymposium.com/index.php?page=2008> (Last Accessed on February 26, 2010).

Kashema, J. (2008). How the DRC could become self-sufficient in fish production. *Agricultural International Magazine /KUL-Belgium* pp.1-45.

Laraque, A., Mahe, G., Orange, D. and Marieu, B. (2001). Spatiotemporal variations in hydrological regimes within Central Africa during the XXth Century. *Journal of Hydrology* 245:104-117.

Musa, I. (2008). Saving Lake Chad – Based on Proceedings of Sirte Roundtable, Libya, 17 Dec. 2008. Lake Chad Basin Commission and International Commission of Irrigation and Drainage. [http://www.afrwg.icidonline.org/save\\_lakechad.pdf](http://www.afrwg.icidonline.org/save_lakechad.pdf) (Last Accessed on August 10, 2010).

NASA. (2010). GISS Precipitation Data. National Aeronautics and Space Administration. [http://data.giss.nasa.gov/precip\\_cru/maps.html](http://data.giss.nasa.gov/precip_cru/maps.html) (Last Accessed on February 25, 2010).

National Geographic. (2010). Fish of the Congo River, National Geographic Website.<http://channel.nationalgeographic.com/series/explorer/3826/Overview> (Last Accessed on February 25, 2010).

Ndala, B. (2009). Congo River Basin: challenges and current initiatives. Presented at the 5th World Water Forum, 2009. [http://www.riob.org/IMG/pdf/03\\_CICOS-PO.pdf](http://www.riob.org/IMG/pdf/03_CICOS-PO.pdf) (Last Accessed on February 25, 2010).

SADC. (2007). Handbook on Environmental Assessment Legislation in the SADC Region. Development Bank of Southern Africa & SAIEA, Midrand. Southern African Development Community. [http://www.saiea.com/dbsa\\_book/index.htm](http://www.saiea.com/dbsa_book/index.htm) (Last Accessed on February 26, 2010).

Showers, K. (2009). Gongo River's Grand Inga hydroelectricity scheme: linking environmental history, policy and impact. *Water History* 1:31-58.

UNEP. (2008). Freshwater Under Threat, Africa. United Nations Environment Programme. Upper Congo Fishes Project. (n.d.). Discovering the Fishes of a Great River. <http://www.congofishes.net/Site/Welcome.html> (Last Accessed on February 25, 2010).

USGS. (2009). A Field Trip to the Congo, Hydroacoustic measurements in "the river that swallows all rivers." Online lecture by John Shelton, Associate Director, Hydrologic Data South Carolina Water Science Center. United States Geological Survey. [http://www.usgs.gov/public\\_lecture\\_series/archive\\_lectures.asp](http://www.usgs.gov/public_lecture_series/archive_lectures.asp) (Last Accessed on February 25, 2010).

World Bank. (2008). Democratic Republic of Congo Growth with Governance In the Mining Sector. Report No. 43402. <http://siteresources.worldbank.org/INTOGMC/Resources/336099-1156955107170/drcgrowthgovernanceenglish.pdf> (Last Accessed on February 25, 2010).

### Juba Shabelle Basin

Thiemig, V. (2009). Early Flood Warning in Africa: Are the Methodologies of the European Flood Alert System (EFAS) Transferable to African Basins? – A Feasibility Study in the Juba-Shabelle River Basin. Masters Thesis, Radboud University Nijmegen, Nijmegen, The Netherlands. <http://floods.jrc.ec.europa.eu/flood-research-at-jrc/flood-forecasting-in-africa> (Last Accessed on May 21, 2010).

FAO. (2005). FAO Aquastat Country Profile, Somalia. Food and Agriculture Organization of the United Nations. <http://www.fao.org/nr/water/aquastat/countries/somalia/index.stm> (Last Accessed on May 21, 2010).

Artan, G., Gadain, H., Muthusi, F., Muchiiri, P. (2007). Improving flood forecasting and early warning in Somalia – a feasibility study. FAO-SWALIM Project publication No W-10. <http://www.faoswalim.org/subsites/frmmis/downloads/W-10%20Improving%20Flood%20Forecasting%20and%20Early%20Warning%20in%20Somalia.pdf> (Last Accessed on May 21, 2010).

### Lake Chad Basin

Boronina, A. and Ramillien, G. (2008). Application of AVHRR imagery and GRACE measurements for calculation of actual evapotranspiration over the Quaternary aquifer (Lake Chad basin) and validation of groundwater models. *Journal of hydrology* 348:98-109.

CIMA Webpage. (n.d.). "CIMA International in Lake Chad". <http://www.international.cima.ca/cgics/cs.waframe.content?click=105396&lang=2> (Last accessed on February 9, 2010).

Coe, T. and Foley, A. (2001). Human and natural impacts on the water resources of the Lake Chad basin. *Journal of Geophysical Research* 106(4):3349–3356.

FAO. (2009). Adaptive Water Management in the Lake Chad Basin, Addressing current challenges and adapting to future needs, World Water Week, Stockholm, August 16-22, 2009. Food and Agriculture Organization of the United Nations.

Giannini, A., Saravanan, R. and Chang, P. (2003). Ocean Forcing of Sahel Rainfall on Interannual to Interdecadal Time Scales. *Science* 302:1027-1030.

GIWA. (2004). Lake Chad Basin, GIWA Regional assessment 43 GIWA Regional assessment reports [GIWA Reg. Assess. Rep.] Global International Waters Assessment. <http://www.unep.org/dewa/giwa/publications/r43.asp> (Last Accessed on August 10, 2010).

Isiorho, S., Matisoff, G., Wehn, K. (1996). Seepage Relationships Between Lake Chad and the Chad Aquifers. *Groundwater* 34(5):819-826.

IUCN. (2003). Waza Logone Floodplain, Cameroon: Economic benefits of wetland restoration. Integrating Wetland Economic Values into River Basin Management. International Union for Conservation of Nature. [http://www.iwlearn.net/abt\\_iwlearn/events/ouagadougou/readingfiles/iucn-restoration-benefits-waza-cameroon.pdf](http://www.iwlearn.net/abt_iwlearn/events/ouagadougou/readingfiles/iucn-restoration-benefits-waza-cameroon.pdf) (Last accessed on February 9, 2010).

IUCN. (2004). Case Studies in Wetland Valuation #4, Waza Logone Floodplain Cameroon: economic benefits of wetland restoration. International Union for Conservation of Nature. <http://cmsdata.iucn.org/downloads/casestudy04waza.pdf> (Last accessed on March 29, 2010).

Lemoalle, J., Bader, J., and Leblanc, M. (2008). The variability of Lake Chad: hydrological modelling and ecosystem services. In: 13th IWRA World Water Congress 2008, 01-04 September 2008, Montpellier, France. <http://eprints.jcu.edu.au/4918/> (Last accessed on February 8, 2010).

Loth, P. (Ed.).(2004). The Return of the Water: Restoring the Waza Logone Floodplain in Cameroon. IUCN, Glard, Switzerland and Cambridge, UK. [http://www.wou.edu/~moritzm/return\\_water.pdf](http://www.wou.edu/~moritzm/return_water.pdf) (Last accessed on March 29, 2010).

Musa, I. (2008). Saving Lake Chad – Based on Proceedings of Sirte Roundtable, Libya, 17 Dec. 2008. Lake Chad Basin Commission and International Commission of Irrigation and Drainage. [http://www.afrwg.icidonline.org/save\\_lakechad.pdf](http://www.afrwg.icidonline.org/save_lakechad.pdf) (Last Accessed on August 10, 2010).

Ngatcha, B., Budry, J., Leduc, C. (2008). Water resources management in the Lake Chad basin: Diagnosis and action plan. In *Applied Groundwater Studies in Africa: IAH Selected Papers on Hydrogeology, volume 13* Editor(s): Segun Adelana, University of Ilorin, Nigeria; Alan MacDonald, British Geological Survey, Edinburgh, Scotland.

Nihoul, C., Zavalov, P., Micklin, P. (2003). Dying and Dead Seas: Climatic versus anthropic causes. North Atlantic Treaty Organization Scientific Affairs Division, NATO Science Series IV, Earth and Environmental Sciences – Vol. 36. 2003. Kluwer Academic Publishers.

Roche, M. (1977). Lake Chad: A subdesertic terminal basin with freshwaters. *ORSTOM*. [http://horizon.documentation.ird.fr/exl-doc/pleins\\_textes/pleins\\_textes\\_6/b\\_fdi\\_35-36/41578.pdf](http://horizon.documentation.ird.fr/exl-doc/pleins_textes/pleins_textes_6/b_fdi_35-36/41578.pdf) (Last accessed on September 10, 2010).

Scholte, P. (2005). Floodplain rehabilitation and the future of conservation & development: Adaptive management of succes in Waza-Logone, Cameroon, PhD. Thesis, Leiden University, The Netherlands. <https://www.openaccess.leidenuniv.nl/handle/1887/4290> (Last accessed on March 29, 2010).

SEDAC. (2010). Gridded Population of the World: Future Estimates. Socioeconomic Data and Applications Center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT <http://sedac.ciesin.columbia.edu/gpw> (Last Accessed on August 10, 2010).

Senay, G., Pengra, B., Bohms, S., Singh, A., Verdin, J. (2010). Africa-wide water balance estimation using remote sensing and global weather datasets. *American Geophysical Conference Fall Meeting*. Submitted.

Shanahan, T., Overpeck, J., Anchukaitis, K., Beck, J., Cole, J., Dettman, D., Peck, J., Scholz, C., King, J. (2009). Atlantic Forcing of Persistent Drought in West Africa. *Science* 324:377-380.

UN-WPP (2008) World Population Prospects: The 2008 Revision, United Nations Population Division. <http://esa.un.org/UNPP/> (Last Accessed on July 20, 2010).

University of Washington. (2009). Joint Institute for the Study of the Atmosphere and Ocean (2009) Sahel rainfall index (20-10N, 20W-10E), 1900 - August 2009. Available online at: <http://jisao.washington.edu/data/sahel/> (Last Accessed on February 9, 2010)

Zhang, R. and Delworth, T. (2006). Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes. *Geophysical Research Letters* 33:L17712

### Lake Turkana Basin

Angeleli, I. (2009) Another African Lake on the Endangered List, Ethiopian Dam Endangers Kenya's Lake Turkana. *World Rivers Review* 24(1):6-7

ARWG. (2009) A Commentary on the Environmental, Socioeconomic and Human rights Impacts of the Proposed Gibe III Dam in the Lower Omo river Basin of Ethiopia by African Resources Working Group. <http://www.arwg-gibe.org/> (Last accessed on April 6, 2009).

EEEPCo. (2009). GIBE III Hydroelectric Project, Environmental and Social Impact Assessment. Ethiopian Electric Power Corporation, 2009.

Haack, B. (1996). Environmental Auditing, Monitoring Wetland Changes with Remote Sensing: An East African Example. *Environmental Management* 20(3):411-419.

ILEC. (n.d.). World Lakes Database. International Lake Environment Committee. <http://www.ilec.or.jp/database/afr/afr-20.html> (Last accessed on April 6, 2009).

Legos. (2005). Fleuves et Lacs du Monde – Veille hydrologique par satellite. <http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/StationsVirtuelles/Turkana.html> (Last accessed on April 6, 2009).

Nicholson, S. (2001). Climatic and environmental change in Africa during the last two centuries. *Climate Research* 17:123-144.

Nyamweru, C. (1989). New evidence for the former extent of the Nile drainage system. *The Geographical Journal* 155:179-188.

ORNL. (2008). LandScan dataset 2008, Oak Ridge National Laboratory. <http://www.ornl.gov/sci/landscan/index.shtml> (Last Accessed on August 10, 2010).

SEDAC. (2010). Gridded Population of the World: Future Estimates. Socioeconomic Data and Applications Center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT. Accessed <http://sedac.ciesin.columbia.edu/gpw> (Last Accessed on August 10, 2010).

### Limpopo River Basin

CGIAR. (2003). Limpopo Basin Profile – ARC-Institute for Soil Climate and Water/ARC-Institute for Agricultural Engineering/IWMI. Consultative Group on International Agricultural Research. [http://www.arc.agric.za/limpopo/pdf/basin\\_profile\\_intro.pdf](http://www.arc.agric.za/limpopo/pdf/basin_profile_intro.pdf) (Last accessed on May 21, 2010).

Reason, C., Hachigonta, S., Phaladi, R. (2005). Interannual variability in rainy season characteristics over the Limpopo region of southern Africa. *International Journal of Climatology* 25:1835-1853.

World Bank (2010). World Bank Development Indicators. [http://www.google.com/publicdata?ds=wb-wdi&met=sp\\_pop\\_grow&idim=country:AGO&dl=en&hl=en&q=An+gola+population+growth+rate#met=sp\\_pop\\_grow&idim=country:MOZ:BWA:ZAF](http://www.google.com/publicdata?ds=wb-wdi&met=sp_pop_grow&idim=country:AGO&dl=en&hl=en&q=An+gola+population+growth+rate#met=sp_pop_grow&idim=country:MOZ:BWA:ZAF) (Last accessed on May 21, 2010).

### Niger River Basin

Adedeji A. and Ako, R.(2009). Towards achieving the United Nations' Millennium Development Goals: The imperative of reforming water pollution control and waste management laws in Nigeria. *Desalination* 248:642-649.

AfDB. (2008). "Kandadji" Ecosystems Regeneration and Niger Valley Development Programme, Detailed Environmental and Social Impact Assessment – Executive Summary. African Development Bank. <http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ADF-BD-IF-2008-51-EN-NIGER-KANDADJI-ECOSYSTEMS-REGENERATION-DETAILED-POPULATION-RESETTLEMENT-PLAN.PDF> (Last accessed on July 20, 2010).

AFD. (n.d.). AfricaPolis: Urbanization study in West Africa (1950-2020) Report from Agence Française de Développement. <http://www.afd.fr/jahia/Jahia/lang/en/home/publications/NotesetEtudes/Africapolis#> (Last accessed on February 24, 2010).

Ajao, E. and Anurigwo, S. (2002). Land-based Sources of Pollution in the Niger Delta, Nigeria. *Ambio* 31(5):442-445.

Amnesty International. (2009). Petroleum, Pollution and Poverty in the Niger Delta. <http://www.amnesty.org/library/asset/AFR44/017/2009/en/e2415061-da5c-44f8-a73c-a7a4766ee21d/af440172009en.pdf> (Last accessed on February 24, 2010).

Anderson, I., Dione, O., Jarosewich-Holder, M., Olivry, J. (2005). The Niger River Basin, A Vision for Sustainable Management. Edited by K.G. Goltzen. Washington D.C.; The World Bank.

BBC. (2009). "Mali villagers fight back against Sahara". <http://news.bbc.co.uk/2/hi/8408568.stm> (Last accessed on September 20, 2010)

BGR. (n.d.). Capacity Building for Groundwater Management in West and Southern Africa. W/Downloads/pbgw\_\_executivesummary.templateId=raw,property=publicationFile.pdf/pbgw\_executivesummary.pdf (Last accessed on February 24, 2010).

CNEARC. (2004). Le lac Faguibine, un espace agropastoral au Nord Mali : Centre National d'Etudes Agronomiques des Régions Chaudes, 1101, avenue Agropolis – BP 5098 - 34033 Montpellier Cedex 01. <http://www.cariassociation.org/gtd/?section=documentation&subsection=gtd> (Accessed on December 15, 2006).

Descroix,L., Mahé,b,G., Lebel,T., Favreau,G., Galle, S., Gautier,E., Olivry J-C., Albergel, J., Amogu, O., Cappelaeere, B., Dessouassi, Diedhiou, R., Le Breton, E., Mamadou, I., and Sighomnou, D. (2009). Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: A synthesis. *Journal of Hydrology* 375(1-2): 90-102.

Giannini, A., Saravanan, R. and Chang, P. (2003). Ocean Forcing of Sahel Rainfall on Interannual to Interdecadal Time Scales. *Science* 302:1027-1030.

Hamerlynck, O., Chiramba, T., Pardo, M. (2009). Gestion des écosystèmes du Faguibine (Mali) pour le bien-être humain : adaptation aux changements climatiques et apaisement des conflits. [http://www.dialoguebarrages.org/dialoguebarrages/index2.php?option=com\\_docman&task=doc\\_view&gid=25&Itemid=39](http://www.dialoguebarrages.org/dialoguebarrages/index2.php?option=com_docman&task=doc_view&gid=25&Itemid=39) (Last accessed on March 30, 2010).

L'Hôte, Y., Mahé, G., Somé, B., Triboulet, J. (2002). Analysis of a Sahelian annual rainfall index from 1896 to 2000; the drought continues. *Hydrological Sciences* 47(4):563-572.

Ludec, C., Favreau, G., Schroeter, P. (2001). Long-term rise in a Sahelian water-table: the Continental Terminal in South-West Niger. *Journal of Hydrology* 243:43-54.

Lutz, A., Thomas, J., Pohl, G., Keita, M., McKay W. (2009). Sustainability of groundwater in Mali, West Africa. *Environmental Geology* 58:1441-1450

Mahé, G., Bamba, F., Soumaguel, A., Orange, D., and Olivry, J. (2009). Water losses in the inner delta of the River Niger: water balance and flooded area. *Hydrological Processes* 23:3157-3160.

Nicholson, S. (1983). Sub-Saharan Rainfall in the Years 1976-80: Evidence of Continued Drought. *Monthly Weather Review*. 111:1646-1654

NNPC (2009) 2009 Third Quarter Petroleum Information – Nigerian National Petroleum Corporation. <http://www.nnpcgroup.com/> (Last accessed on February 24, 2010).

OSS. (2008). Iullemeden Aquifer System (Mali, Niger, Nigeria): concerted management of shared water resources of a sahelian transboundary aquifer. Tunis, Tunisia; Sahara and Sahel Observatory (OSS).

Ramsar. (2004). Mali designates Inner Niger Delta for the Ramsar List. [http://www.ramsar.org/cda/ramsar/display/main.jsp?zn=ramsar&cp=1-63-78%5E18383\\_4000\\_0\\_\\_](http://www.ramsar.org/cda/ramsar/display/main.jsp?zn=ramsar&cp=1-63-78%5E18383_4000_0__) (Last accessed on February 24, 2010).

Ramsar. (2010). The List of Wetlands of International Importance – 28 January 2010. <http://www.ramsar.org/pdf/siteslist.pdf> (Last accessed on February 23, 2010).

Shanahan, T., Overpeck, J., Anchukaitis, K., Beck, J., Cole, J., Dettman, D., Peck, J., Scholz, C., King, J. (2009). Atlantic Forcing of Persistent Drought in West Africa. *Science* 324:377-380.

UNEP. (n.d.). Rehabilitating Lake Faguibine Ecosystem – Project Fact Sheet. United Nations Environment Programme. [http://www.unep.org/Themes/freshwater/PDF/Factsheet\\_LakeFaguibine.pdf](http://www.unep.org/Themes/freshwater/PDF/Factsheet_LakeFaguibine.pdf) (Last accessed on March 30, 2010).

UNEP. (2007). Dams and Development Project Compendium on Relevant Practices, Social Impact Assessment of Affected People. <http://www.unep.org/DAMS/includes/compendium.asp> United Nations Environment Programme. (Last accessed on February 23, 2010).

Vandersypen, K., Verbist, B., Keita, A., Raes, D., Jamin, J. (2009). Linking Performance and Collective Action-the Case of the Office du Niger Irrigation Scheme in Mali. *Water Resource Management* 23:153-168.

Yo-Essien, L. (2008). Oil Spill Management in Nigeria: Challenges of Pipeline Vandalism in the Niger Delta Region of Nigeria. Presented at 15th Annual International Petroleum & Biofuels Environmental Conference, Nov. 10-13 2008, Albuquerque, NM. [http://ipec.utulsa.edu/Conf2008/Manuscripts%20&%20presentations%20received/Eyo\\_Essien\\_2.pdf](http://ipec.utulsa.edu/Conf2008/Manuscripts%20&%20presentations%20received/Eyo_Essien_2.pdf) (Last accessed on February 23, 2010).

Zhang, R. and Delworth, T. (2006). Impact of Atlantic multidecadal oscillations on India/Sahel rainfall and Atlantic hurricanes. *Geophysical Research Letters* 33:L17712.

Zwarts, L., Van Beukering, P., Kone, B. & Wymenga, E. (2005). The Niger, a Lifeline: Effective Water Management in the Upper Niger Basin. Lelystad, Sévare, Amsterdam, Veenwouden: RIZA, Wetlands International, Institute for Environmental Studies (IVM), Altenburg & Wymenga Ecological Research.

Zwart, S. and Leclert, L. (2009). A remote sensing based irrigation performance assessment: a case study of the Office du Niger in Mali. *Irrigation Science* (in press)

### Nile River Basin

Ahmad, A. (2008). Post-Jonglei planning in southern Sudan: combining environment with development. *Environment and*

- Kiwango, Y. and Wolanski, E. (2008). Papyrus wetlands, nutrients balance, fisheries collapse, food security, and Lake Victoria level decline in 2000-2006. *Wetlands Ecology Management* 16:89-96.
- Krishnamurthy, V. (1980). The Impact Forseen of the Jonglei Canal Scheme on The Fisheries on the Sudd Region: The Problems and Solutions. In CIFA Technical Paper No. 8: Seminar on River Basin Management and Development, Blantyre, Malawi, 8-10 December.
- Kull, D. (2006). Connections Between Recent Water Level Drops in Lake Victoria, Dam Operations and Drought. Hydrologic Engineer, Nairobi, Kenya.
- Laki, S. (1994). The impact of the Jonglei Canal on the economy of the local people. *International Journal of Sustainable Development and World Ecology*, 1:89-96
- Lahmeyer Int. (n.d). Merowe Dam and Hydropower Plant - Lahmeyer International Engineering and Consulting Services Website. <http://www.lahmeyer.de/en/projects/details/browse/0/project/298/mode/1/show/showAll/> (Last accessed on September 20, 2010).
- Lehman, J. (2009). Lake Victoria. In: Dumont, H.J. (ed) *The Nile: Origin, Environments, Limnology and Human Use*, Springer Science, 2009.
- Machiwa, P. (2003). Water quality management and sustainability: the experience of Lake Victoria Environmental Management Project (LVEMP)—Tanzania. *Physics and Chemistry of the Earth* 28:1111-1115.
- Minakawa, N., Sonye, G. Dida, G.O., Futami, K., Kaneko S. (2008). Recent reduction in the water level of Lake Victoria has created more habitats for Anopheles funestus. *Malaria Journal* 7:119.
- Moussa, A. and Bethmann F. (2007). Case study Merowe / Hamdab Dam Project. From the seminar The Science and Politics of Large Dam Projects – Swiss Federal Institute of Aquatic Science and Technology. [http://www.eawag.ch/research\\_e/apec/seminars/Case%20studies/2006/Merowe-dam.pdf](http://www.eawag.ch/research_e/apec/seminars/Case%20studies/2006/Merowe-dam.pdf) (Last accessed September on 20, 2010).
- NBI. (2005a). National Nile Basin Water Quality Monitoring Baseline Report for Sudan. Nile Basin Initiative. [http://nile.riverawarenesskit.com/French/NRAK/Resources/Document\\_centre/WQ\\_Baseline\\_report\\_Sudan.pdf](http://nile.riverawarenesskit.com/French/NRAK/Resources/Document_centre/WQ_Baseline_report_Sudan.pdf) (Last accessed on July 20, 2010).
- NBI. (2005b). National Nile Basin Water Quality Monitoring Baseline Report for Egypt. Nile Basin Initiative. [http://nile.riverawarenesskit.com/French/NRAK/Resources/Document\\_centre/WQ\\_Baseline\\_report\\_Egypt.pdf](http://nile.riverawarenesskit.com/French/NRAK/Resources/Document_centre/WQ_Baseline_report_Egypt.pdf) (Last accessed on July 20, 2010).
- Nicholson, S. and Yin, X. (2000). On the feasibility of using a lake water balance model to infer rainfall: an example from Lake Victoria. *Hydrological Sciences* 45(1):75-95.
- Njiru, M., Kazungu, J., Ngugi, C.C., Gichuki, J., Muhozi, L. (2008). An overview of the current status of Lake Victoria fishery: Opportunities, challenges and management strategies. *Lakes and Reservoirs: Research and Management* 13:1-12.
- SEDAC. (2010). Gridded Population of the World: Future Estimates. Socioeconomic Data and Applications Center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT. <http://sedac.ciesin.columbia.edu/gpw> (Last accessed on August 10, 2010).
- Scheren, P., Zanting, H., Lemmens, A. (2000). Estimation of water pollution sources in Lake Victoria, East Africa: Application and elaboration of the rapid assessment methodology. *Journal of Environmental Management* 58:235-248.
- Stanley, D. and Warne, A. (1993). Nile Delta: Recent Geological Evolution and Human Impact. *Science* 260:628-634.
- Sudan Tribune. (2009). Jonglei canal project needs to be revised, South Sudan says. <http://www.sudantribune.com/spip.php?article32062> (Last accessed September on 20, 2010)
- Sutcliffe, J. and Petersen, G. (2007). Lake Victoria: derivation of a corrected natural water level series. *Hydrological Sciences* 52(6):1316-1321.
- Swensen, S. and Wahr, J. (2009). Monitoring the water balance of Lake Victoria, East Africa from space. *Journal of Hydrology* 370:163-176.
- UN News Centre (2006). UN agency hails inclusion of vast wetlands in south Sudan on conservation list. *UN News Centre*. <http://www.un.org/apps/news/story.asp?NewsID=20439&Cr=sudan&Cr1> (Last accessed on December 14, 2007).
- UNESA. (2007). The 2006 Revision and World Urbanization Prospects: The 2007 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects*: <http://esa.un.org/unup> (Last accessed on September 20, 2010).
- UNESA. (2008). Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2008 Revision*, <http://esa.un.org/unpp> (Last accessed on September 20, 2010).
- UNEP. (2007). Sudan Post-Conflict Environmental Assessment. United Nations Environment Programme, Nairobi, Kenya.
- USAID. (2009). Cooperation and competition: Managing Transboundary Water Resources in the Lake Victoria Region. United States Agency for International Development. Working Paper No. 5.
- Yoffe, S., Wolf, A., Giordano, M. (2003). Conflict and Cooperation over international freshwater resources: Indicators of Basins at Risk. *Journal of the American Water Resources Association* 39(5):1109–1126.
- Yongo, E., Keizire, B., Mbilinyi, B. (2008). Socio-economic Impacts of Fish Trade. In *The State of the fisheries Resources of Lake Victoria and Their Management – Proceedings of the Regional Stakeholders’ conference*, Entebbe, 24th-25th February 2005).
- Wahaab, R. and Badawy M. (2004). Water Quality Assessment of the river Nile System: An Overview. *Biomedical and Environmental Sciences* 17:87-100.
- WaterTech. (n.d.). “Toshka Project – Mubarak Pumping Station / Sheikh Zayed Canal, Egypt” <http://www.water-technology.net/projects/mubarak/> (Last accessed on September 20, 2010).
- Williams, A., Duthie, H., Hecky, R. (2005). Water hyacinth in Lake Victoria: Why did it vanish so quickly and will it return? *Aquatic Botany* 81:300-314.
- Ogooué River Basin**
- SEDAC. (2010). Gridded Population of the World: Future Estimates. Socioeconomic Data and Applications Center (SEDAC); collaboration with CIESIN, UN-FAO, CIAT. <http://sedac.ciesin.columbia.edu/gpw> (Last accessed on August 10, 2010).
- Laurance, W., Alonso, A., Lee, M., Campbell, P. (2006). Challenges for forest conservation in Gabon Central Africa. *Futures* 38:454-470.
- The Okavango Delta Basin**
- Gieske, A. (1997). Modelling outflow from the Jao/Boro River System in the Okavango Delta, Botswana. *Journal of Hydrology* 193:214-239.
- Scudder, T. (2008). Okavango River Basin. In, *Water Resources Development and Management* of Transboundary Rivers and Lakes. Eds. Varis, O., Tortajada, C. and Biswas, A.K. <http://www.springerlink.com/content/10184t6h40l31v85/fulltext.pdf> (Last accessed on May 21, 2010).
- Ramberg, L., Hancock, P., Lindholm, M., Meyer, T., Ringrose, S. Sliva, J., Van As, J., VanderPost, C. (2006). Species diversity of the Okavango Delta, Botswana. *Aquatic Sciences* 68:310-337.
- SAIEA. (2009). Pre-Feasibility Study for the Popa Falls Hydro Power Project: Preliminary Environmental Assessment - Impact Assessment Case Studies from Southern Africa. [http://www.saiea.com/case\\_studies09/08%20PopaFallsHydropower.pdf](http://www.saiea.com/case_studies09/08%20PopaFallsHydropower.pdf) (Last accessed on May 21, 2010).
- Orange River Basin**
- Earle, A., Malzbender, D., Turton, A., Manzungu, E. (2005). A Preliminary Basin Profile of the Orange/Senqu River. AWIRU, University of Pretoria, South Africa. [http://www.acwr.co.za/pdf\\_files/05.pdf](http://www.acwr.co.za/pdf_files/05.pdf). (Last accessed on May 21, 2010).
- SADC-GTZ. (2007). Orange River Integrated Water Resources Management Plan, Prepared for the Orange Senqu River Commission (ORASECOM). <http://www.orasecom.org/publications/iwrm+plan.aspx> (Last accessed on May 21, 2010).
- Senay, G., Pengra, B., Bohms, S., Singh, A., Verdin, J. (2010). Africa-wide water balance estimation using remote sensing and global weather datasets. *American Geophysical Conference Fall Meeting*. Submitted.
- Senegal River Basin**
- Bà, A. (2004). Case 1: Parc National Du Diawling. In: Report of the African Pre-Conference on water for food and ecosystems, Addis Ababa, 4-6 Nov. 2004. [http://www.fao.org/ag/wfe2005/docs/annex\\_d.pdf](http://www.fao.org/ag/wfe2005/docs/annex_d.pdf) (Last accessed on October 17, 2007).
- Barbiérou, L., Mohamedou, A., Laperrouzaz, C., Furian, S., Cunnac, S. (2004). Polyphasic origin of salinity in the Senegal delta and middle valley. *Catena* 58:101-124.
- Boivin, P., Maeght, J., Hammecker, C., Barbiérou, L., Favre, F., Wopereis, M. (1998). Evolution of irrigated soils in the Senegal river valley: alkaline or neutral salinization process? Paper presented at: 16e ISSS World Congress, August, 1998. <http://nates.psu.ac.th/Link/SoilCongress/bdd/symp29/1260-T.pdf> (Last accessed on March 8, 2007).
- Connor, D., Comas, J., Gómez-Macpherson, H., Mateos, L. (2008). Impact of small-holder irrigation on the agricultural production, food supply and economic prosperity of a representative village beside the Senegal River, Mauritania. *Agricultural Systems* 96:1-15.
- DeGeorges, A. and Reilly, B. (2006). Dams and Large Scale Irrigation on the Senegal river. Impacts on Man and the Environment. Case Study for 2006 Human Development Report. UNDP.
- Duvail, S. and Hamerlynck, O. (2003). Mitigation of negative ecological and socio-economic impacts of the Diama dam on the Senegal River Delta wetland (Mauritania), using a model based decision support system. *Hydrology and Earth System Sciences* 7(1):133-146.
- Fall, O., Hori, N., Kan, H., Diop, M. (2003). Toward an Integrated Management Plan of the Djoudj Park Water Resources: Senegal River Mouth. *Environmental Management* 31(1):14-28.
- FAO. (1997). Irrigation potential in Africa: A basin approach – FAO Land and Water Bulletin –4. Food and Agriculture Organization of the United Nations. <http://www.fao.org/docrep/w4347e/w4347e00.htm> (Last accessed on February 24, 2010).
- Horowitz, M. and Salem-Murdoch, M. (1993). Development-Induced Food Insecurity in the Middle Senegal Valley *GeoJournal* 30(2):179-184.
- IR. (1999). A Case Study on the Manantali Dam Project (Mali, Mauritania, Senegal). International Rivers. <http://www.internationalrivers.org/en/africa/case-study-manantali-dam-project-mali-mauritania-senegal> (Last accessed on March 8, 2010).
- Isupova, M. and Mikhailov, V. (2008). Hydrological and Morphological Processes in Senegal River Mouth Area. *Water Resources* 35(1):30-42.
- Lahtela, V. (2003). Managing the Senegal River: National and Local Development Dilemma. *Water Resources Development* 19(2):279-293.
- Lebel, T. and Ali, A. (2009). Recent trends in the Central and Western Sahel rainfall regime (1990-2007). *Journal of Hydrology* 375:52-64.
- Mietton, M., Dumas, D., Hamerlynck, O., Kane, A., Coly, A., Duvail, S., Pesneaud, F., Baba, M. (2007). Water management in the Senegal River Delta: a continuing uncertainty. *Hydrological Earth Systems Sciences Discussions* 4:4297-4323.
- OMVS. (n.d.). Aménagements hydroagricoles. L’Organisation pour la mise en valeur du fleuve Sénégal website. <http://www.omvs.org/fr/realisations/irrigation.php> (Last accessed on September 27, 2010).
- Poussin, J. and Boivin, P. (2002). Performances des systemes rizicoles irrigues sahéliens. *Cahiers Agricoles* 11:65-73.
- Tappan, G., Sall, M., Wood, E., Cushing, M. (2004). Ecoregions and land cover trends in Senegal. *Journal of Arid Environments* 59(3):427-462.
- Van Asten, P., Barbiérou, L., Wopereis, M., Maeght, J., van der Zee, S. (2003). Actural and Potential salt-related soil degradation in an irrigated rice scheme in the Saheliann zone of Mauritania. *Agricultural Water Management* 60:13-32.
- Verhey, W. (1995). Impact of climate and soil conditions on conception and implementation of irrigation schemes in the Senegal River basin. *Agricultural Water Management* 28:73-94.
- Wopereis, M., Ceuppens, J., Boivin, P., Ndiaye, A., Kane, A. (1998). Preserving soil quality under irrigation in the Senegal River Valley. *NJAS wageningen. Journal of Life Sciences*, Vol 46(1):1-8.
- UNDP. (2009). Human Development Report – Overcoming Barriers: Human mobility and development. United Nations Development Programme. <http://hdr.undp.org/en/reports/global/hdr2009/> (Last accessed on March 8, 2010).
- UNESCO. (2003). World Water Report: Water for People, Water for Life- Chapter 20 Senegal River Basin, Guinea, Mali, Mauritania, Senegal. United Nations Educational, Scientific and Cultural Organization. [http://www.unesco.org/water/wwap/wwdr/wwdr1/table\\_contents/index.shtml](http://www.unesco.org/water/wwap/wwdr/wwdr1/table_contents/index.shtml) (Last accessed on March 8, 2010).
- UNESCO. (n.d.) List of World Heritage in Danger. United Nations Educational, Scientific and Cultural Organization. <http://whc.unesco.org/archive/repcom00.htm#djoudj> (Last accessed on March 8, 2010).
- WMO. (2004). Integrated Flood Management Case Study Mauritania: Managed Flood Releases and Livelihoods – Lower Delta Senegal river. World Meteorological Organization. [http://www.apfm.info/pdf/case\\_studies/cs\\_mauritania.pdf](http://www.apfm.info/pdf/case_studies/cs_mauritania.pdf) (Last accessed on March 8, 2010).
- Volta River Basin**
- Barry, B., Obuobie, E., Andreine, M., Andah, W., Pluquet, M. (2005). The Volta River Basin, Comprehensive Assessment of Water Management in Agriculture – Comparative study of river basin development and management. IWMI. [http://www.iwmi.cgiar.org/assessment/files\\_new/research\\_projects/River\\_Basin\\_Development\\_and\\_Management/VoltaRiverBasin\\_Boubacar.pdf](http://www.iwmi.cgiar.org/assessment/files_new/research_projects/River_Basin_Development_and_Management/VoltaRiverBasin_Boubacar.pdf) (Last accessed on September 20, 2010).
- Zambezi River Basin**
- Beiffuss, R., and Brown, C. (2006) Assessing Environmental Flow Requirements for the Marrameu complex of the Zambezi Delta. Museum of Natural History – University of Eduardo Mondlane, Maputo, Mozambique. <http://www.internationalrivers.org/files/Beiffussfinalreport.pdf> (Last accessed on March 25, 2010).
- CEH. (2001). Managed Flood Releases: A working conference on guidelines for managed flood releases and lessons learned from Itzhi-tezhi. Lusaka 13-14 March 2001. Center for Ecology and Hydrology, Workshop Report.
- Chenje, M. (2000) State of the Environment Zambezi Basin 2000. SADC/IUCN/ZRA/SDRDC, Maseru/Lusaka/Harare, 2000.
- Davies, B., Beiffuss, R., Thoms, M. (2000). Cahora Bassa restrospective, 1974-1997: effects of flow regulation on the Lower Zambezi River. *Verh. Internat. Verein. Limnol.* 27:1-9.
- ETH. (2004). Zambezi River Basin, from: ETH Seminar: Science and Politics of International Freshwater Management 2003/2004. Swiss Federal Institute of Technology Zurich. [http://www.eawag.ch/research\\_e/apec/seminars/Case%20studies/2003/Zambezi.pdf](http://www.eawag.ch/research_e/apec/seminars/Case%20studies/2003/Zambezi.pdf) (Last accessed on March 25, 2010).
- IR. (2006). “Damning the Zambezi – Risks outweigh benefits of proposed Mphanda Nkuwa Dam.” International Rivers. <http://www.internationalrivers.org/en/node/846> (Last accessed on March 25, 2010).
- IFPRI. (2009) The Impact of climate Variability and change on Economic Growth and Poverty in Zambia. International Food Policy Research Institute. <http://www.ifpri.org/publication/impact-climate-variability-and-change-economic-growth-and-poverty-zambia> (Last accessed on March 25, 2010).
- Magadza, C. (n.d.). Kariba Reservoir, Experience and Lessons Learned Brief. [http://www.worldlakes.org/uploads/14\\_Kariba\\_Reservoir\\_27February2006.pdf](http://www.worldlakes.org/uploads/14_Kariba_Reservoir_27February2006.pdf) (Last accessed on March 25, 2010).
- Magadza, C. (2006). Kariba Reservoir: Experience and lessons learned. *Lakes and Reservoirs: Research and Management* 11:271-286.
- Manatsa, D., Chingombe, W., Matarira, C. (2008). The impact of the positive Indian Ocean dipole on Zimbabwe droughts. *International Journal of Climatology* 28:2011-2029.
- Marshall, B. and Junor, F. (1981). The decline of *Salvinia molesta* on Lake Kariba. *Hydrobiologia* 83:477-484.
- McDermott-Hughes, D. (2006). Whites and Water: How Euro-Africans Made Nature at Kariba Dam. *Journal of Southern African Studies* 32(4):823-838.
- Moore, A., Cotterill, F., Main, P., Williams, H. (2007). The Zambezi River. In *Large Rivers: Geomorphology and Management*. Edited by A Gupta, Chichester, UK. 2007, John Wiley & Sons.
- Morrissey, J. (2006). Livelihoods at Risk: The case of the Mphanda Nkuwa Dam - Community risk assessment for the proposed Mphanda Nkuwa hydroelectric dam. <http://www.internationalrivers.org/files/MphandaRA2006.pdf> (Last accessed on March 25, 2010).
- Ngalande, P. (2004) Country Review Zambia. In: Proceedings of the International Workshop on the Fisheries of the Zambezi Basin, Livingstone, Zambia 31 May – 2 June 2004. [http://www.worldfishcenter.org/resource\\_centre/CP75\\_301007.pdf](http://www.worldfishcenter.org/resource_centre/CP75_301007.pdf) (Last accessed on March 25, 2010).
- Nicholson, S. and Kim, J. (1997). The Relationship of the El Niño-Southern Oscillation to African Rainfall. *International Journal of Climatology* 17:117-135.
- Schelle, P. and Pittock, J. (2005). Restoring the Kafue Flats, A partnership approach to environmental flows in Zambia. Presented at 10th International Riverssymposium & Environmental Flows Conference, Brisbane, Australia, September 3, 2005.
- Scudder, T. (2005). The Kariba Case Study. *Social Science Working Paper* 1227 – California Institute of Technology.
- UTIP. (n.d). Unidade Técnica de Implementação Dos Projectos Hidroeléctricos. <http://www.utip.org.mz/home/index.htm> (Last accessed on March 25, 2010).
- WWF. (2007). Towards Effective Conservation Strategies – The application of strategic principles to increase the impact and sustainability of WWF conservation efforts. Prepared by AID Environment for WWF Netherlands, WWF US & WWF UK. World Wildlife Fund. [http://assets.panda.org/downloads/wwf\\_nl\\_strategic\\_principles\\_03\\_29\\_07.pdf](http://assets.panda.org/downloads/wwf_nl_strategic_principles_03_29_07.pdf) (Last accessed on June 6, 2007).
- Transboundary Aquifers**
- BRGM. (2005). Hydrogeological Map of Africa: a prototype at 1/10 000 000 scale. Bureau de Recherches Géologiques et Minières. [http://www.sigafrique.net/datawebmaster/doc/Carte\\_Hydro\\_Afrique.pdf](http://www.sigafrique.net/datawebmaster/doc/Carte_Hydro_Afrique.pdf) (Last accessed on July 15, 2010).
- Salman, S. (1999). Groundwater, Legal and Policy Perspectives. Proceedings of a World Bank seminar (November 1999). Washington, World Bank. WBTP 456.
- UNESCO. (2001). Internationally Shared (Transboundary) Aquifer Resources Management. Their significance and sustainable management. A framework document. IHP-VI, IHP Non Serial Publications in Hydrology. November 2001, UNESCO, Paris.
- UNESCO. (2004). Managing shared aquifer resources in Africa. United Nations Educational, Scientific and Cultural Organization.
- UNESCO - IHP/ISARM. (2004). Managing Shared Aquifer Resources in Africa. IHP-VI, Series on Groundwater 8. United Nations Educational, Scientific and Cultural Organization International Hydrological Programme. Internationally Shared Aquifer Resources Management. <http://www.isarm.net/publications/299> (Last accessed on July 15, 2010).
- Nubian Sandstone Aquifer**
- Abdelrhem, I., Rashid, K., Ismail, A. (2008). Integrated Groundwater Management for Great Man-Made River Project in Libya. *European Journal of Scientific Research* 22(4):562-569.
- Alghariani, S. (2007). Reducing Agricultural Water Demand in Libya through Improving Water Use Efficiency and Crop Water Productivity. Proceedings of WRM 2007, Honolulu Hawaii.
- Alker, M. (2008). The Nubian Sandstone Aquifer System. In: Conceptualizing cooperation on Africa’s transboundary groundwater resources. Ed: Walina Scheumann and Elke Herrfahrdt-Pähle. German Development Institute. <http://www.isn.ethz.ch/isn/Current-Affairs/Security-Watch/Detail/?q51=Mali&ots591=0c54e3b3-1e9c-be1e-2c24-a6a8c706233&lng=en&id=103285> (Last accessed on May 21, 2010).
- Bakhbakhi, M. (2006). Nubian Sandstone Aquifer System. In: Non-Renewable Groundwater Resources – A guidebook on socially-sustainable management for water-policy makers. Eds. S. Foster and D. Loucks. UNESCO 2006.
- CEDARE. (2001). Regional Strategy for the Utilisation of the Nubian Sandstone Aquifer System – Executive Summary. Centre for Environment and Development for the Arab Region and Europe – International Fund for Agricultural Development. Cairo, CEDARE 2001.
- Dakhleh Oasis Project (n.d.) Dakhleh Oasis Project – Monash University Department of Archaeology webpage. <http://arts.monash.edu.au/archaeology/excavations/dakhleh/index.php> (Last accessed on May 21, 2010).
- Ebraheem, A., Riad, S., Wycisk, P., Seif El-Nasr, A. (2003). Simulation of impact of present and future groundwater extraction from the non-replenished Nubian Sandstone Aquifer in southwest Egypt. *Environmental Geology* 43:188-196.
- Eggemont, H., Verschuren, D., Fagot, M., Rumes, B., Van Bocxlaer, B. (2008). Aquatic community response in a groundwater-fed desert lake to Holocene desiccation of the Sahara. *Quaternary Science Reviews* 27:2411-2425.
- Ghazali, A. and Abounahia, M.(2005). An Optimum Approach for the Utilization of the Great Man-Made River Water in Libya. Proceedings Ninth International Water Technology conference, IWTC9, 2009 Sharm El-Sheikh, Egypt.
- Gossel, W., Ebraheem, A., Wycisk, P. (2004). A very large scale GIS-based groundwater flow model for the Nubian sandstone aquifer in Eastern Sahara (Egypt, northern Sudan and eastern Libya) *Hydrogeology Journal* 12:698-713.
- Grenier, C., Paillou, P. and Maugis, P. (2009). Assessment of Holocene surface hydrological connections for the Ounianga lake catchment zone (Chad). *C.R. Geoscience* 341:770-782.
- Heinl, M. and Brinkman, P. (1989). A groundwater model of the Nubian aquifer system. *Hydrological Sciences Journal* 34(4):425-447.
- Hughes, R. and Hughes, J. (1992). A Directory of African Wetlands. IUCN, Gland, Switzerland/ UNEP, Nairobi, Kenya/WCMC, Cambridge, U.K.
- Kröpelin, S. (2007) The Saharan lakes of Ounianga Serir-A unique hydrological system. In: Bubner, O., Bolten, A. & Darius, F. (eds.) (2007): Atlas of Cultural and Environmental Change in Arid Africa. Africa Praehistorica 21. Cologne.
- Kröpelin, S., Verschuren, D., Lézine, A.-M., Eggemont, H., Cocquyt, C. Francus, P., Cazet, J.-P., Fagot, M., Rumes, B., Russell, J., Darius, F., Conley, D., Schuster, M., von Suchodoletz, H. Engstrom, D. (2008). Climate-Driven Ecosystem Succession in the Sahara: The Past 6000 Years. *Science* 320:765-768.
- Kröpelin, S. (2009). Lakes in the Sahara. *German Research February* 2009.
- Shahin, M. (1987). Groundwater resources in Egypt: potentials and limitations. *Water for the Future: Hydrology in Perspective* (Proceedings of the rome Symposium, April 1987). IAHS Publ. no. 164.
- Shaki, A. and Adelaye, A. (2006). Evaluation of quantity and quality of irrigation water at Gadowa irrigation project in Murzuq Basin, southwest Libya. *Agricultural Water Management*. 84:193-201.
- UNESA. (2008). World Population Prospects: The 2008 Revision Population Database. Department of Economic and Social Affairs. <http://esa.un.org/unpp/index.asp?panel=3> (Last accessed on May 21, 2010).
- Water Technology.net (n.d.) “GMR (Great Man-made river) Water Supply Project, Libya.” <http://www.water-technology.net/projects/gmr/> (Last accessed on May 21, 2010).
- World Bank. (2010). World Bank Development Indicators. [http://data.worldbank.org/data-catalog/world-development-indicators?cid=GPS\\_WDI](http://data.worldbank.org/data-catalog/world-development-indicators?cid=GPS_WDI) (Last accessed on July 21, 2010).
- Coastal Aquifers**
- Elbadawy, O. (2007) Management of Shared Aquifer using GIS: A regional case study, Nubian Sand Stone Aquifer. Environmental technologies, including GIS, environmental simulation and process simulation. December 10-12 2007, Tunis, Tunisia.
- Hinrichsen D. 1995. Coasts in Crisis. American Associate for the Advancement of Science (AAAS), Washington D.C. USA. <http://www.aaas.org/international/ehnfisheries/hinrichs.htm> (Last accessed on May 21, 2010).
- Schlumberger Water Services. (2007). Groundwater Modeling in the Al Kufrah Basin and the Al Jaghbub Area – Case Study. [http://www.waterloohydrogeologic.com/e\\_news/guest\\_articles/Kufra-Jaghboub-Case-Study.pdf](http://www.waterloohydrogeologic.com/e_news/guest_articles/Kufra-Jaghboub-Case-Study.pdf) (Last accessed on May 21, 2010).
- Steyl, G. and Dennis, I. (2010). Review of coastal-area aquifers in Africa. *Hydrogeology Journal* 18:217-225.
- UNEP. (2008). Africa Atlas of Our Changing Environment. United nations Environment Programme. Division of Early Warning and Assessment. Nairobi.
- Tano Basin Abidjan Aquifer**
- Oga, M., Marlin, C., Dever, L., Filly, A., Njitichoua, R. (2008). Hydrochemical and isotopic characteristics of coastal groundwater near Abidjan (southern Ivory Coast). In *Applied Groundwater Studies in Africa – Sequun Adelana and Alan MacDonal* editors, Taylor and Francis 2008.

# CHALLENGES & OPPORTUNITIES

## 3

