THE CONSERVATION CONDITION OF THE UNPROTECTED OKAVANGO DELTA, BOTSWANA

By

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LIST OF ABBREVIATIONS

- Biological Oxygen Demand = BOD
- Chemical Oxygen Demand = COD
- Department of Water Affairs and Forestry (South Africa) = DWAF
- Department of Water Affairs (Botswana) = DWA
- Dissolved Organic Carbons = DOC
- Dissolved Oxygen = DO
- Electrical Conductivity = EC
- European Union = EU
- Geographical Positioning System = GPS
- Gross Domestic Product = GDP
- Okavango Delta Management Plan = ODMP
- Okavango Fish Parasite Project = OFPP
- Okavango River Panhandle Management Plan = ORPMP
- Total Dissolved Solids/Salts = TDS
- Total Organic Carbons = TOC
- Trihalomethane = THM
- Water Research Commission (South Africa) = WRC
- Water Utilities Corporation (Botswana) = WUC
- Wildlife Management Area = WMA

Chapter 1

INTRODUCTION

The Okavango Delta is a spectacular wetland, situated in the heart of the semi-arid Kalahari Desert of southern Africa. The Okavango River's journey starts in the highlands of Angola, where it flows as many tributaries, before entering Namibia's Caprivi Strip as a single river. On reaching the border between Namibia and Botswana, the Okavango floods an area known as the Panhandle, between two north-south geological faults. One hundred kilometres downstream, the waters of the Okavango reach the east-west Gumare Fault, spilling across the sands of the Kalahari and creating a beautiful, life-supporting oasis.

The Ramsar Convention is a global treaty, which aims at conserving wetlands of international importance and value. When a country or member countries declare a wetland as a Ramsar site, they recognise that that particular wetland has extreme importance and value and agree to actively strive to conserve it (Pallett 1997). Currently, the total number of sites designated for the Ramsar list is 1880, covering a total surface area of 184,966,347 hectares. The Okavango Delta Ramsar site covers an area of 5,537,400 hectares (Fig. 1.1) and includes Lake Ngami. It ranks among the top five largest Ramsar sites in the world, with only the Ngiri-Tumba-Maindombe in the Democratic Republic of Congo, the Queen Maud Gula in Canada, the Grands affluents in Congo and the Sudd in Sudan being larger (Ramsar Convention Secretariat 2009).

Due to the Okavango Delta’s large surface area, diverse habitats and complexity, it is a difficult wetland to conserve. Although it is a Ramsar site and we tend to think of it as a single unit, it is not an isolated or clearly defined place with a fence around it such as the Kruger National Park, which is easier to conserve and has limited issues. The Delta is dependent on the upstream Okavango River and can not be managed properly without the co-operation of the other two states sharing the basin. It is common knowledge that what takes place upstream will affect what happens downstream, but so will what is done in the downstream area itself.

In Botswana, the management paradigm of the system is that the central core, the Moremi Reserve, is a conservation area with minimal human intervention. However, large parts of the wetland, and in my opinion probably the most vulnerable, are unprotected. These include the western part of the Delta Fan, the entire Panhandle, as well as Lake Ngami. The unprotected Okavango Delta and, consequently, the protected Delta, face pressure from several processes as a result of an increasing human population and the accompanying greater demand for space and resources, especially water.

Figure 1.1: Board erected close to Mohembo indicating that one is entering the Okavango Delta Ramsar site, which should be managed and protected, following its inclusion in the Ramsar list of wetlands of international importance (courtesy of the Aquatic Parasitology Research Group, UFS). The site area, as indicated on this board, is incorrect. The actual size is 5,537,400 hectares.

The number of people and their livestock has increased rapidly in the basin over the past few years, especially in Kavango and Ngamiland (Mendelsohn and El Obeid 2004). The questions that arise are:

- How did human activities change in the unprotected Okavango Delta in the last two decades?
- How, if at all, did it influence the water quality of the system?
- How, if at all, did it affect the ecological integrity of the system?
- Given that so many people rely on untreated water, which they collect directly from the river for survival, is the water fit for human consumption?

In order to present any conclusion concerning the conservation condition of the Okavango wetland, it is important to include the water quality of the system and to consider the factors which may have a negative impact on the water quality or the system as a whole. We are fortunate that 23 years ago a study was done on the water quality of the Lower Panhandle. This was used to compare results and determine if any water quality changes have taken place.

A paper was published by Hart (1997) in which he presents a limnological profile of the Okavango Panhandle based on data collected at the southern end of the Panhandle (in the vicinity of Seronga) in 1986. He collected samples in the mainstream of the Panhandle, from just above the upstream opening to Seronga Lagoon, down to Etstatsa. Furthermore, he took samples at various sites in both Seronga Lagoon and Dungu Lagoon. As his study only took place during a brief period, no consideration of the seasonal hydrograph could be accomplished.

Using this paper as baseline, our aim was not only to revisit his well documented study sites, but also to expand on the study as well as to answer the aforementioned questions. Thus, we collected data along the entire Panhandle and beyond, from Popa Falls in Namibia to Guma Lagoon in the north-western corner of the Delta Fan, as well as at Lake Ngami. Furthermore, this study also includes different levels of flooding to determine seasonal water quality changes, if any.

This study will serve as a contribution to broadening the Okavango Fish Parasite Project's (OFPP) ecological perspectives, as parasites may have negative effects on fish when the latter are stressed under conditions of bad water quality. The OFPP was initiated by scientists from the University of the Free State in response to the government of Botswana expressing concern over a sudden decline in Okavango fish populations in the late 1990s.

The parasitological study aimed at determining the biodiversity and distribution of fish parasites in the Okavango, as well as the effect it may have on fish. The project was approved in 1997 and is being conducted in collaboration with other universities in South Africa, as well as the Harry Oppenheimer Okavango Research Centre, University of Botswana. This project has been ongoing for the last 12 years and has already resulted in many publications, conference contributions, workshops presented to government officials and postgraduate studies. The water quality of this system, however, is the major contributing factor to the health status of the entire wetland.

In order to manage and conserve the Okavango Delta and its aquatic and terrestrial plants and animals, it is important to know the climatic conditions of the area, as well as the history and functioning of the system. These conditions, general water-related issues and background information on Africa as a dry continent, along with a physical description of the basin, are given in **Chapter 2**. The material and methods used are explained in **Chapter 3**. In this chapter our research base, study sites, field trips and the methods used to collect and analyse data are discussed. **Chapter 4** briefly describes the different microbiological, physical and chemical parameters which were tested for and also gives the water quality results obtained during the study. Remarks are made in this chapter concerning the water quality results that were obtained. In order to understand the overall conservation condition of the Okavango Delta, it is important to touch on a couple of issues threatening its pristine status. These issues either took place in the past, are taking place at present, or possibly will take place in the future and could have serious negative impacts on, not only the water quality, but the overall conservation condition of the Okavango Delta. **Chapter 5** is the concluding chapter in which these issues are dealt with. This dissertation ends with the references in **Chapter 6**, followed by the abstracts, acknowledgements and appendix.

Chapter 2

PAST AND PRESENT OF THE OKAVANGO SYSTEM: IN AN AFRICAN CONTEXT

AFRICA: THE DRY CONTINENT

Africa is undoubtedly one of the most ecologically rich continents in the world and has a variety of ecosystems that have always been under regular, complex and unpredictable change (Mung'ong'o 2009). We now find ourselves at a time when the impact of ecosystem changes are becoming clear, not only globally, but also, more importantly, at national and community levels (Kangalawe 2009).

Deforestation has become the major problem of our time and has intensified the extent of climate change, desertification, loss of habitats and biological diversity, and the deterioration of aquatic ecosystems (Mung'ong'o 2009). Many African communities are highly dependent on ecosystems and the resources they provide for their livelihoods. This means that any changes in the ecosystem in which they live may have a considerable impact on their well-being (Kangalawe 2009).

Ecosystems do not only provide us with natural resources, but with a number of other services as well. These ecosystem services include supporting, provisioning, regulating and cultural services. Supporting services consist of, amongst others, nutrient cycling, soil formation and primary production. Natural resources such as food, freshwater, wood, fibre and fuel are some of the provisioning services ecosystems provide, while ecosystems also regulate climate, floods, and diseases, not to mention that ecosystems purify water as well (regulating services). To top it all ecosystems provide us with aesthetic, spiritual, educational and recreational services too (cultural services). There are linkages of varying intensity between ecosystem services and human well-being, such as security, basic material for a good life, health and good social relations (The United Nations Environment Programme 2005).

This called for governments to formulate policies, pass legislation and set up various institutions addressing these issues. Political ecology was developed and starts from the principle that there is a basic interdependence between society and the natural world in which its people live (Mung'ong'o 2009). Kangalawe (2009) states that many ecosystems, especially in Africa, have undergone huge changes associated with a number of drivers of bio-physical and socio-economic nature. He goes on to explain that the bio-physical drivers can be associated with global change or changes in landscapes, due to geomorphic processes. These processes can be triggered by, amongst others, tectonic forces. Socio-economic drivers are factors that boost some of the bio-physical processes, for example vegetation degradation, soil erosion and over-exploitation of resources. An important driver of socio-economic change is an ever increasing human population, which leads to an increased demand on space and resources, especially water.

At this day and age rapid population growth is probably the greatest threat to humanity and the environment. Many of the problems of over-exploitation and the misuse of natural resources unfortunately have to do with unfair practices or social inequities and it is a sad truth of modern society that the wealthier one is and the higher one's standard of living, the more one wastes. Yes, many environmental problems are caused by poverty, but it is equally true that wealth causes just as many problems, if not more. A good example of this is the use of water. In a squatter camp on the Cape Flats (in South Africa), for example, a family of eight who fetch their water from a tap a few hundred metres away will use about 120 litres of water per day. In nearby Cape Town, a couple living in an up-market suburb, with a big garden, will probably use more than 2000 litres per day (Pallett 1997). We should ask ourselves then, who is causing the water supply shortage?

Despite the issues of unfairness in water consumption, it cannot be denied that the rapidly increasing population is making things worst, not only in supplying water, but all other natural resources for that matter.

The threat of uncontrolled population growth is illustrated by the biological principle of carrying capacity, which, in human terms, is expressed as the number of people an area can support and sustain, without permanent damage being caused to the natural environment. Obviously, a population that wastes and pollutes much of the resources available to it, lowers the carrying capacity of its natural environment. Less water (and other natural resources) becomes available to each person as that population increases and this is exactly what is happening in the world today. As people get increasingly desperate to make a living and survive, crime, social tensions and conflicts set in (Pallett 1997).

Physical evidence of the population explosion in southern Africa, as well as the rest of the world, can be seen in the increasing demand for clean water, agricultural land, raw materials and employment, as well as in the increasing need to use artificial means to boost productivity, such as: chemical fertilizers on crops, hormonal growth boosters for farm animals and irrigation of crops in marginal areas. These demands have ever-widening side-effects such as the:

- increasing use of fertilizers and pesticides which pollute water and soil;
- increasing amounts of human and animal 'sewage' which need to be treated and, therefore, require more water and increase the danger of pollution;
- increasing water, soil and air pollution from our growing number of mines and industries;
- increasing overgrazing by domestic animals, farming on marginal land and soil degradation and erosion;
- increasing sedimentation in storage dams, causing their storage capacity to decrease;
- increasing water abstraction for activities such as irrigation, industry and energy generation; as well as the
- decreasing ability of the soil, water and air to sustain humans, fauna and flora (Pallett 1997).

The trends of increasing demands on our natural resources and the declining ability of the environment to supply the needs of humanity are in direct conflict (Pallett 1997). This brings us back to the issue of available clean water, especially in southern Africa.

Water is undoubtedly our most precious natural resource. The presence of water on planet earth is one of the key components to life being possible on this globe, along with a few others. Besides the fact that all organisms need water for drinking, it is also vital for the production and sustainability of food resources, whatever that may be for a particular organism. For humans, at this day and age, the importance of water stretches beyond drinking, eating and cooking. Human populations across the globe have grown to such an extent that we are totally reliable on agriculture and the rearing of domestic animals for our food supplies, which all use considerable amounts of water. We need water to produce our electricity, for our industries and for cleaning (hygiene). Sometimes we even need water for transport and as if that’s not enough we use our limited supply of freshwater for sport and recreation as well! Whether we realise it or not, water plays a great part in our every-day lives and to some, it has a deeper value than just survival. In certain religions water is used to baptise people and some churches use ‘Holy Water’ in rituals.

Most of us in “developed” countries take clean, safe water for granted. We open one of the many taps in and around our homes and we have water which can be used for all household activities! We never stop to think how much it cost to get it there, what processes it went through, how much was left behind for the sustainability of the environment from which it was abstracted, how many other people have never used a tap or even seen one and we even fail to wonder if it is safe for us to use or not – it all just gets taken for granted.

With global warming becoming an increasing threat, our water supplies in places where they normally could be found are not guaranteed and on continents and in countries where water is commonly scarce, this problem can have devastating effects. Take Africa for example: Africa is commonly known as “the dry continent” and has, amongst others, three major deserts that cover more than a third of the continent. These major deserts are the Sahara, Namib and Kalahari. It is often said that “Africa is not for sissies” and this is true in many ways, but despite Africa being so ‘harsh’ there are a number of large river systems and lakes throughout the continent that are vital to life and bring relief to many living here. None of Africa’s major river basins fall within the boundaries of a single country only, instead they are all shared by a number of countries (Table 2.1).

The international boundaries of Africa (Fig. 2.1) originated from the scramble to obtain territories, by the colonial powers in the 19th century and were determined through bilateral negotiations and by using clear geographic features, such as mountain peaks, watersheds or river courses (Pallett 1997). Africans, amongst whom there are at least 2,000 different languages and between 6,000 and 10,000 political or social entities, each of which once had its own governance and legal system, its leadership and customs and culture, played no part in the creation of their nation states. Their boundaries were drawn on maps by Europeans, most of whom had never been to Africa and who had no regard for existing political systems and boundaries (Dowden 2008). Similarly, the concept of keeping river basins within territory boundaries simply never entered the issue and when a half a century later Africans were given flags and national anthems, schools and politicians, and told they were now independent they were also left to resolve issues pertaining water resources shared amongst them.

There are fifteen major rivers in southern Africa all of which are shared between different countries of the Southern African Development Community (SADC) (Table 2.1). The large number of countries that overlap some of the basins emphasizes the importance of jointly managing these international rivers (Pallett 1997). It is common knowledge that what takes place upstream affects what happens downstream, i.e. whatever occurs higher up in the river or in the basin affects the quality and quantity of water lower down.

Table 2.1: River basins of southern Africa and the countries sharing them (compiled from Pallet 1994).

River basin	Number of states	Riparian countries
Buzi	2	Zimbabwe, Mozambique
Cunene	2	Angola, Namibia
Cuvelai	2	Angola, Namibia
Incomati	3	South Africa, Swaziland, Mozambique
Limpopo	4	Botswana, South Africa, Zimbabwe, Mozambique
Maputo	3	South Africa, Swaziland, Mozambique
Nile	10	Tanzania, Burundi, Rwanda, Kenya, Uganda, Zaire, Eritrea, Ethiopia, Sudan, Egypt
Okavango	4	Angola, Namibia, Zimbabwe, Botswana
Orange	4	Lesotho, South Africa, Botswana, Namibia
Pungué	2	Zimbabwe, Mozambique
Rovuma	3	Tanzania, Malawi, Mozambique
Save	2	Zimbabwe, Mozambique
Umbeluzi	2	Swaziland, Mozambique
Zaïre	9	Burundu, Rwanda, Central African Republic, Tanzania, Cameroon, Congo, Zaïre, Zambia, Angola
Zambezi	8	Angola, Namibia, Botswana, Zimbabwe, Zambia, Malawi, Tanzania, Mozambique

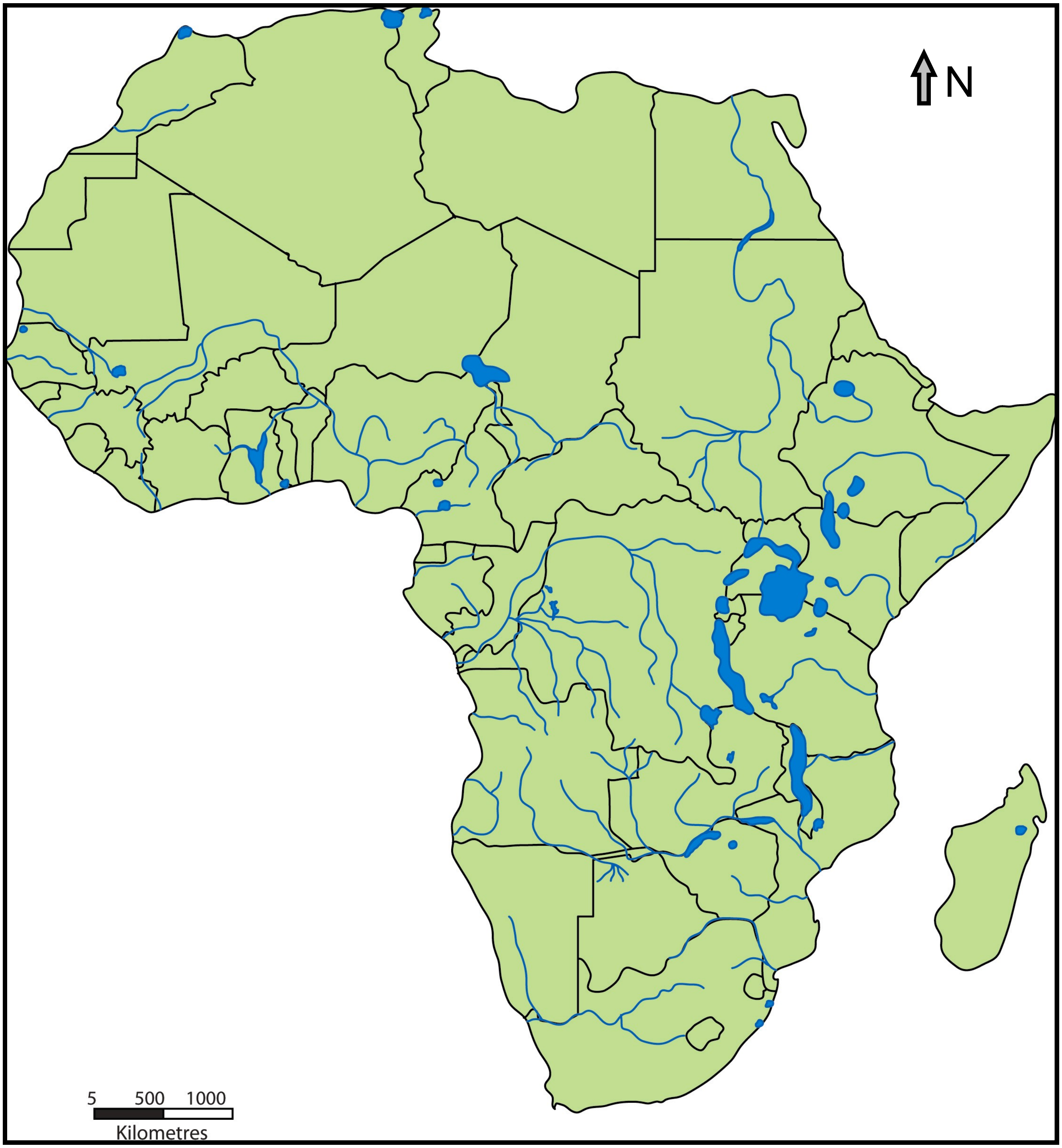


Figure 2.1: International boundaries, rivers and lakes of Africa. These boundaries were drawn up by Europeans in the 19th century through bilateral negotiations and by using clear geographic features, thereby not considering keeping river basins within territory boundaries. Hence, all Africa's major river basins are shared amongst countries (courtesy of the Aquatic Parasitology Research Group, UFS).

Water flows downward through the landscape from high-lying areas to lower areas and finally to the ocean, or to end in an inland basin and on this journey to its end-point; water is shared between different users and is used in various ways. All these users expect their 'fair share' of the resource and it must not be forgotten that the natural environment is a legitimate user of water as well (Pallett 1997). Ecological processes and natural resources also deserve an allocation of the total volume of water, because without enough of it they cease to function effectively and without it, as is the case with people, they cease to function at all.

Management of water resources should consider an entire river basin as a unit, and is best done using an integrated approach so that the sharing of water is equitable, efficient and sustainable (Pallett 1997)

The truth is that southern Africa is suffering from water stress. Pallett (1997) describes a 'flow unit' (equivalent to one million cubic metres of water per year) as a theoretical box with dots in it, each dot representing 100 people (Fig. 2.2) He states that, on average, water stress is not evident in a society where there are less than 600 persons per flow unit (in other words, where there are less than six dots in a box). Beyond that figure, though, there will be signs of water stress and if the population keeps growing it will be approaching absolute water scarcity.

In 1990, the number of people living in water stressed countries worldwide, i.e. countries with more than 600 people per flow unit, was estimated as 300 million. Sadly, this number is expected to increase to over 3 000 million by the year 2025. Most of these people will be living in Africa and South Asia. The next few decades will, therefore, see increasing competition between countries sharing international river basins. The most troublesome of Africa's rivers are probably the Nile, Zambezi and Limpopo Rivers and most of the countries sharing these rivers are likely to suffer chronic water scarcity by then (Pallett 1997).

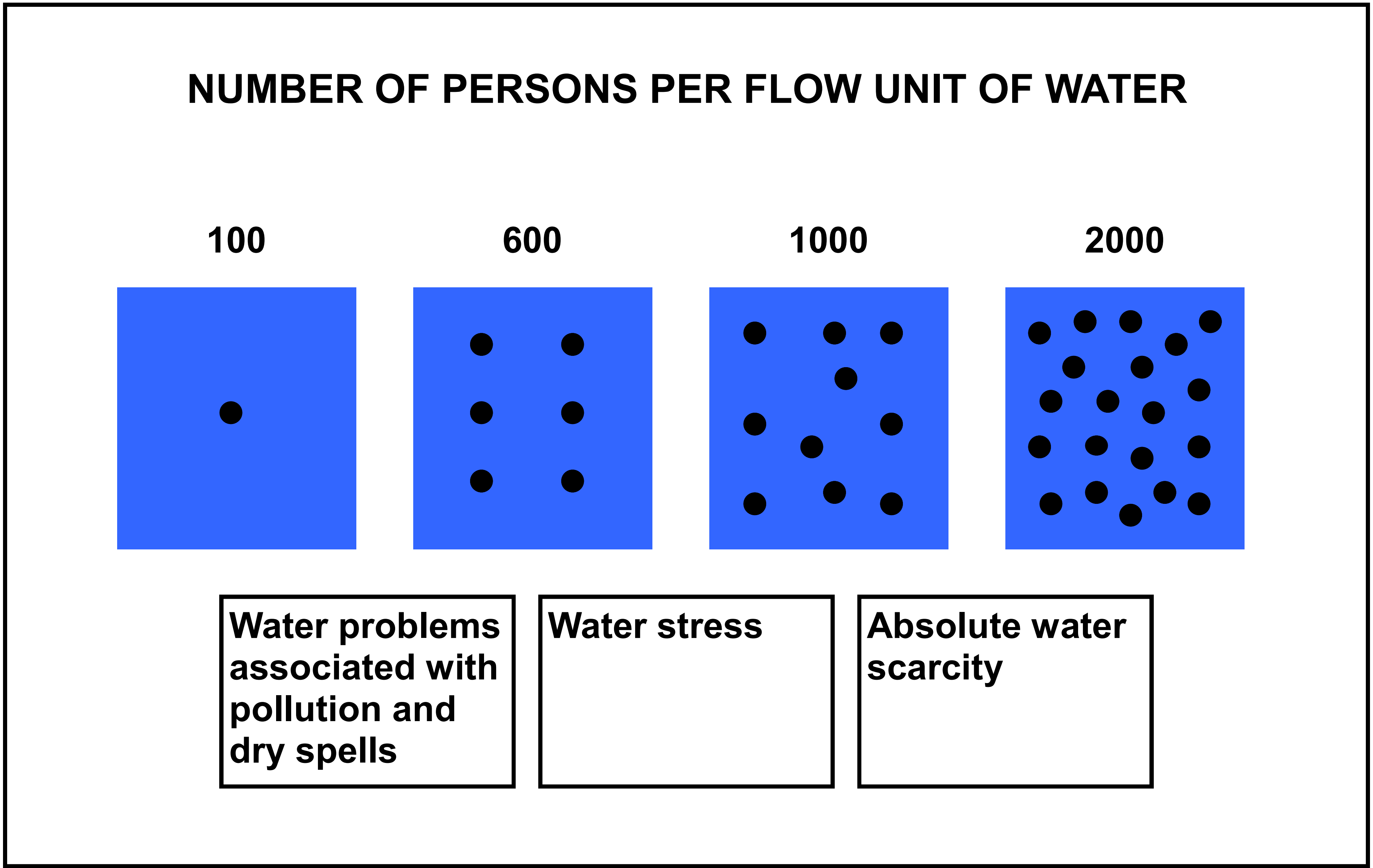


Figure 2.2: Illustrating a 'flow unit' (one million cubic metres of water per year) as a theoretical box with dots in it, each dot representing 100 people. Below 600 people per flow unit water stress is not evident, except were there is pollution or dry spells. Above that figure, signs of water stress set in and absolute water scarcity may be reached (redrawn from Pallet 1997).

There are three major reasons, besides pollution and bad management (that are worth mentioning) for the current and future water stress in southern Africa. The first reason is probably the rapid population growth in the region. Pallett (1997) states that in 1997 over 130 million people were living in southern Africa, but the region has one of the fastest growing populations in the world, with growth rates between 2.2 and 3.6 % per annum and at rates as high as these, the population doubles or even triples every 20 to 30 years. This means that food production, amongst others, will have to increase at the same rate to keep up the current pace, but will have to lift even more to eliminate the shortages that already exist. The hopes of providing people, as well as the natural environment, with their water needs, will continue to drop if southern Africa's population continues to increase at the present rapid rate.

The second and third notable reasons for southern Africa's water stress both have to do with the climate in the region – erratic and unpredictable rainfall as well as its natural aridity due to various factors. Throughout the region, rain falls in the summer months, with the exception of the southern tip of the continent, where rain falls mainly in the winter months. Thus, the year is divided into a dry season and a wet season across most of the region. Annual rainfall generally is higher near the equator and decreases as one moves south. Rainfall also decreases from east to west. Pallett (1997) states that this east-west trend is only apparent south of the 20° parallel (Fig. 2.3). The rainfall range for each of the southern African countries is less than the potential evaporation range for those countries (Table 2.2).

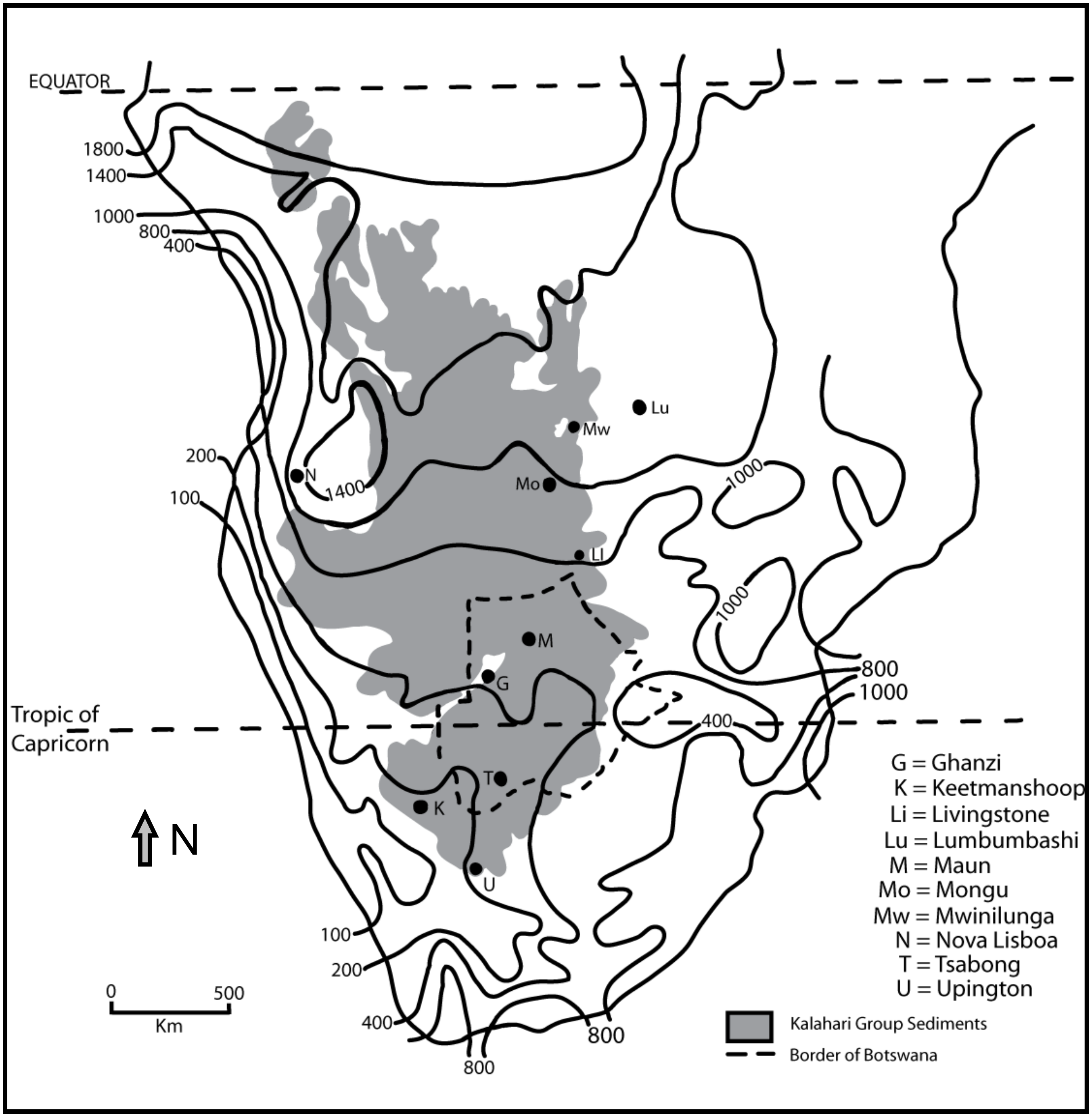


Figure 2.3: Mean annual rainfall (mm) over southern Africa and selected towns in the Kalahari Basin. Rainfall decreases to the south from the equator and also from east to west (south of the 20° parallel) (redrawn from Thomas & Shaw 1991).

Table 2.2: Rainfall (mm) and potential evaporation (mm) ranges for southern African countries (compiled from Pallet 1997).

Country	Rainfall Range (mm)	Average Rainfall (mm)	Potential Evaporation Range (mm)	Total Surface Runoff (mm)
Angola	25 - 1600	800	1300 - 2600	104
Botswana	250 - 650	400	2600 - 3700	0.6
Lesotho	500 - 2000	700	1800 - 2100	136
Malawi	700 - 2800	1000	1800 - 2000	60
Mozambique	350 - 2000	1100	1100 - 2000	275
Namibia	10 - 700	250	2600 - 3700	1.5
South Africa	50 - 3000	500	1100 - 3000	39
Swaziland	500 - 1500	800	2000 - 2200	111
Tanzania	300 - 1600	750	1100 - 2000	78
Zambia	700 - 1200	800	2000 - 2500	133
Zimbabwe	350 - 1000	700	2000 - 2600	34
Total		**7800**		**972.1**

It is important to note that the runoff for each country is generally less than 20 % of the rainfall, which means that most of the rain (more than two thirds) is lost to the atmosphere as evaporation and transpiration. To top it all, the certainty of rain actually falling in the wet season is not high, as rainfall is variable, not only in terms of the volume that falls, but also in terms of its timing during the wet season. These factors vary even more in the drier areas, meaning that, not only is the rainfall less in the more arid climates, but it is also less reliable. This rainfall variability is one of the basic characteristics of the southern African climate and therefore, there is a constant risk of recurrent droughts in the region. A lack of rainfall can occur in different ways or over different time scales. Aridity sets in when there is a permanent situation of low rainfall and high evaporation rates, like in the Namib Desert, while a drought can occur when the rainfall is lower than usual over one or a few years. Due to the naturally variable rainfall pattern, dry spells can occur even during the expected wet season (Pallett 1997).

Droughts clearly form part of the typical southern African climatic pattern and with large parts of the region receiving less than 1,000 mm of rain each year, having high evaporation rates and high rainfall variability, they are classified as sub-humid, semi-arid and arid and are, therefore, desert areas, embracing the hyper-arid Namib Desert, the Karoo, the Kalahari Desert and the intervening areas of the Great Escarpment and southern African Highveld (Pallett 1997; Thomas and Shaw 1991).

The area in which this study was conducted lies within, which is probably the most captivating of all Africa's deserts – the Kalahari Desert.

THE KALAHARI DESERT

The Kalahari Desert lies in the heart of southern Africa and stretches for hundreds of kilometres (Fig. 2.4). Sand dominates this characteristically flat landscape and there is almost no surface water, except after rain, which is erratic in the area. According to Ross (2003), sand is perhaps one of nature's harshest habitats, as it drains any water that touches its surface like a sponge. Over millennia this slow, but sure, seepage of water through the Kalahari Sands has taken with it nutrients, leaving a sandy soil.

In the Kalahari there are vast differences in the landscape between dry and wet seasons and changes are brought about by cycles of drought and abundant rainfall. The Kalahari environment is, therefore, one of substantial contrasts and the subtle balances between its geology, soils, vegetation, fauna and climate determine its distinctive and changing character (Thomas and Shaw 1991).

GEOLOGICAL HISTORY

According to Thomas and Shaw (1991) the initial development of the Kalahari as a geological unit was closely related to the evolution of the African continent, from the division of the super-continent, Gondwanaland, in the Mesozoic.

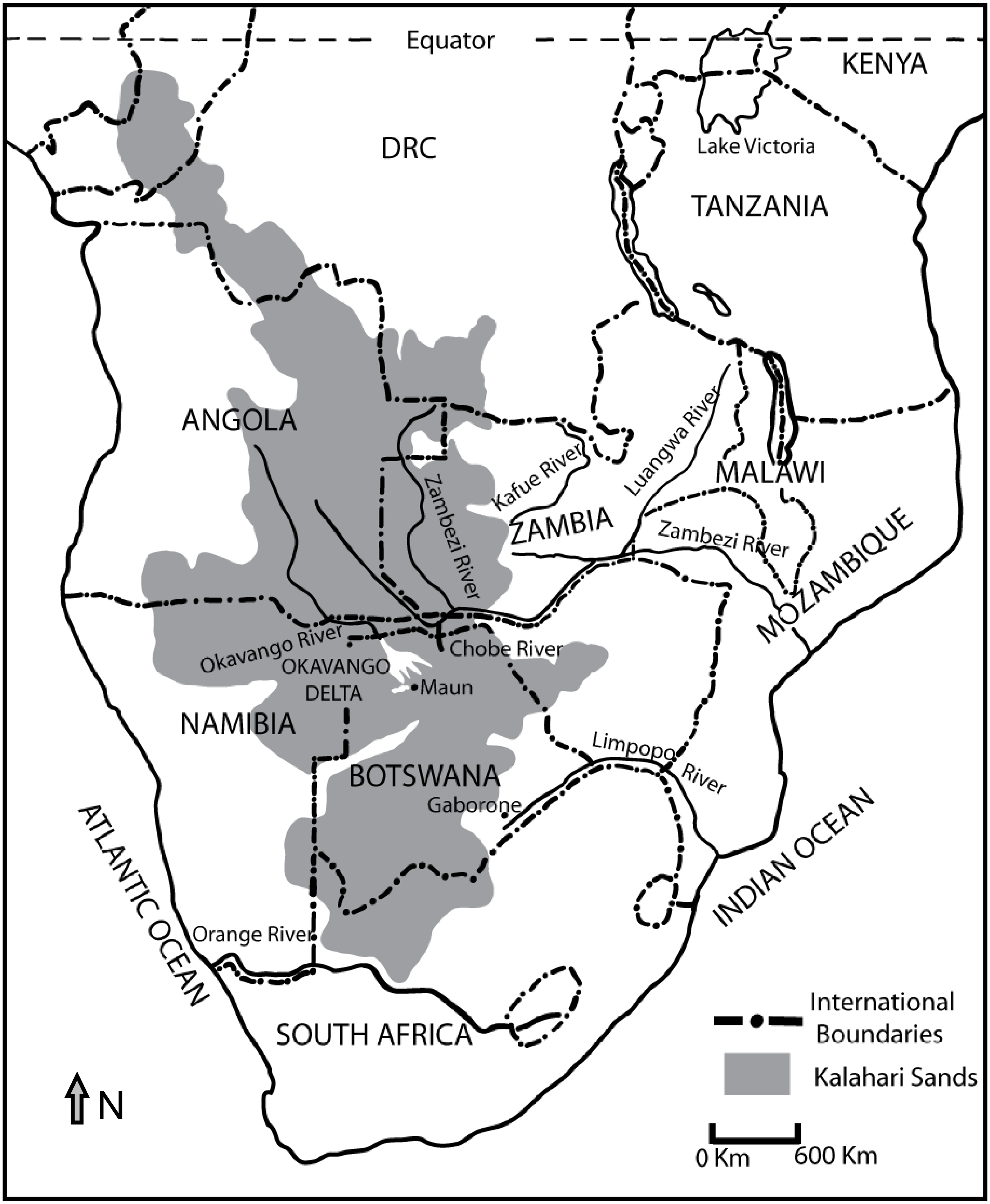


Figure 2.4: The Kalahari Desert which stretches for hundreds of kilometres in the heart of southern Africa and the position of the Okavango River and Delta within the Kalahari (redrawn from Ross 2003).

Tectonic activity at the beginning of the splitting of Gondwanaland involved some rifting in south-eastern Africa, which influenced the nature of sedimentation in parts of southern Africa (Fig. 2.5). Later earth movements during the final division of Gondwanaland, which took place during the mid-Jurassic to early Cretaceous, were generally gentler. This allowed for downwarping in both the coastal zone and the African interior. The latter is responsible for the development of the adjoining Kalahari-Cubango-Congo basin (Fig. 2.5), in which Kalahari sediments accumulated.

THE KALAHARI CLIMATE

The Kalahari climate has a distinct seasonality and is characterized by very hot summers and by winters with warm days and cold nights. Table 2.3 shows the mean daily temperatures during the wet season and during the dry season for selected locations in the Kalahari and figure 2.3 indicates the positions of these locations on a map, as well as the mean annual rainfall (mm) over southern Africa. Variations in precipitation contribute more to the seasonal contrasts in climate than temperature does, making it more appropriate to talk in terms of wet and dry seasons, rather than summer and winter.

The whole of the Kalahari Desert is essentially a summer rainfall zone, with over 80% of precipitation in most of the region occurring mainly between October and April, the summer months. In Botswana, rains commonly only begin in late November and last until April. The mean annual rainfall increases from about 150 mm in the driest south-western areas, to about 650 mm in the north-eastern corner of Botswana, while regions in Zaïre receive up to 1,243 mm per annum (Thomas and Shaw 1991). Rain mostly comes in the form of spectacular thunderstorms, which tend to occur late in the afternoon and during early evening. As mentioned by Thomas and Shaw (1991), while most rainfall comes from high-intensity showers, not every shower is a major event, as analysis of Botswana data shows that over 80 % of rainfall events are low in intensity and

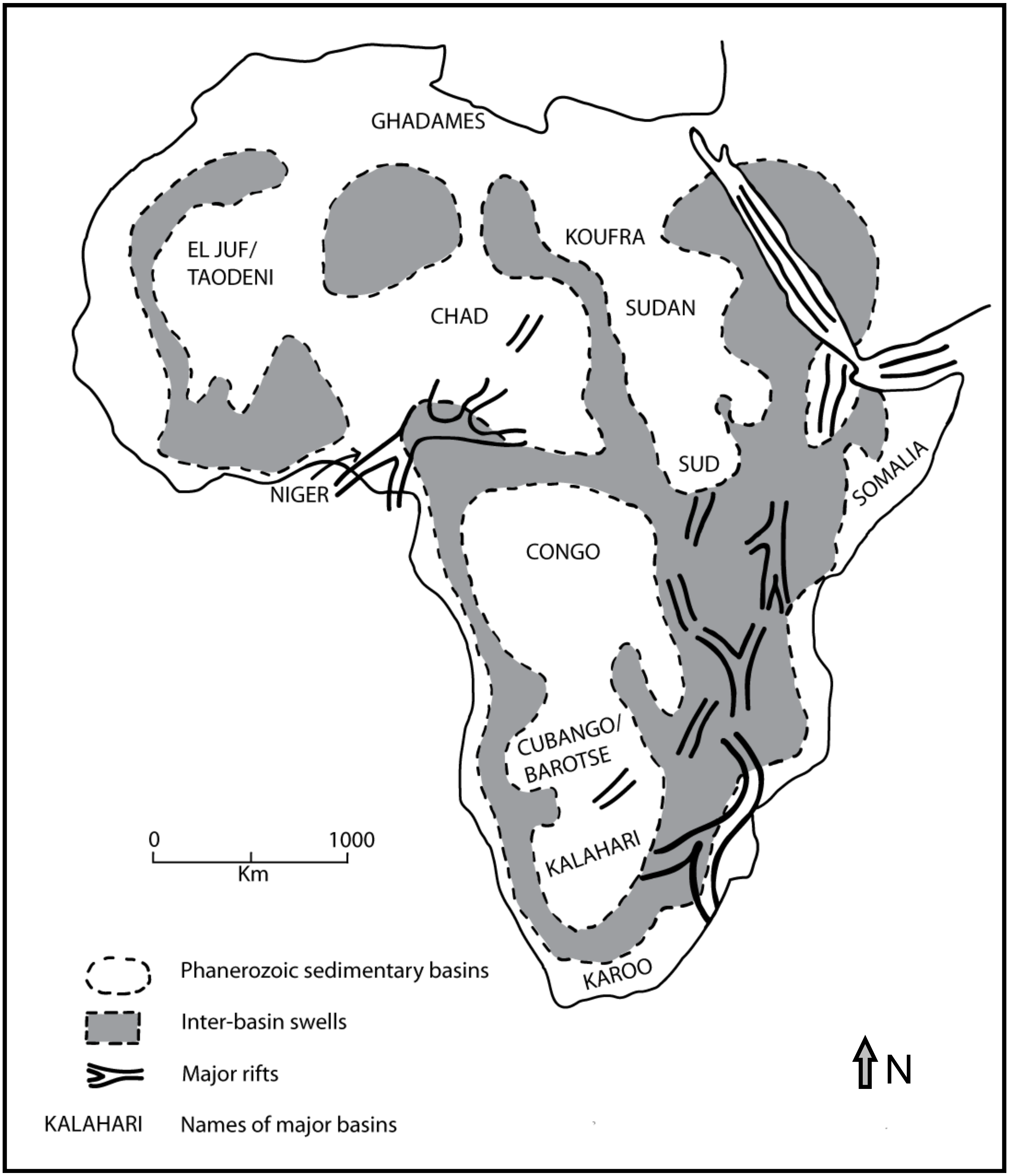


Figure 2.5: Major rifts, swells and sedimentary basins (or major structural trends) of Africa, including the adjoining Kalahari-Cubango-Congo Basin. At the beginning of the splitting of Gondwanaland, rifting took place in south-eastern Africa, which influenced the nature of sedimentation in parts of southern Africa (redrawn from Thomas & Shaw 1991).

Table 2.3: Mean daily temperatures (°C) during wet and dry seasons as well as annual potential evapotranspiration (mm) for selected locations within the Kalahari Basin (compiled from Thomas & Shaw 1991).

Location	Daily mean temperatures (°C)					Temperature extremes (°C)		mean sunshine (h)	Annual potential evapotranspiration (mm)
	Overall mean	Wet season		Dry season					
		Max.	Min.	Max.	Min.	Max.	Min.		
Upington (Oct.-Apr.)	21.9	32	16.7	22.8	5.8	43	-8	10.3	3805
Tsabong (Oct.-Apr.)	19.5	32.1	15.2	24.4	3.6	42	-11	10.6	NA
Keetmanshoop (Nov.-Apr.)	21	32.3	16	23.8	8	42	-4	10.7	3903
Ghanzi (Oct.-April)	20.5	31.7	14.5	26.2	6.4	42	-7	9.8	3305
Maun (Oct.-May)	22	35.5	18.6	28	8.5	43	-6	9.1	3058
Mongu (Oct.-Apr.)	22.5	29.6	18.1	28.4	12	39	-2	8	2313
Mwinilunga (Oct.-Apr.)	20	30.7	15.7	27.4	8.8	35	-1	6.8	NA

NA = Not Available

rainfall volumes are less than 10 mm for about half of the total number of showers.

EVAPORATION AND TRANSPIRATION RATES

Not only does low rainfall contribute to the Kalahari's aridity, but also high potential evapotranspiration rates. The low relative humidity and warm to hot temperatures mean that average annual potential evapotranspiration rates are high, rates increasing towards the southwest, where values exceed 4000 mm per annum. In most parts, evaporation rates well in excess of 2000 mm per annum prevail and in the south-western Kalahari the potential evaporation is between four and ten times the annual rainfall (Thomas and Shaw 1991). Table 2.3 indicates the annual potential evapotranspiration (mm) for each of the selected sights within the Kalahari.

CHANGES IN RAINFALL PATTERNS

Besides the factors mentioned above, the most potentially significant fundamentals of climatic variability in the Kalahari are changes in rainfall patterns over time. Some of the early Europeans who visited the Kalahari during the mid-nineteenth century made notes suggesting that the Kalahari was a well watered place, at least in parts. These observations led later investigators to suggest that the Kalahari, and southern Africa as a whole, was experiencing a progressive increase in dryness, while closer investigation of meteorological records has indicated the incidence of a noteworthy 18-year cycle of fluctuations in rainfall over the summer rainfall zone of southern Africa. Even though the degree and precise periodicity varies to some extent within the area as a whole, the overall trend can be identified in all locations (Thomas and Shaw 1991).

VEGETATION COVER

Thomas and Shaw (1991) state that soils which evolved from Kalahari Sand have been and can be described as skeletal or 'weakly developed, if at all'. The coarse grains of sand are harsh and it is difficult to live and move around in it. It pitilessly reflects the warmth of the sun and is carried away by wind, if not stabilized by vegetation (Ross 2003). These sediments are very low in organic material and nutrients and in such conditions vegetation communities tend to be resilient, adaptive and low in species diversity (Thomas and Shaw 1991). Biodiversity in the Kalahari is regarded as being naturally low in species diversity and is dynamic over space and time, but regardless of such natural absence and difficulty, biodiversity remains important as a part of livelihood strategies, as a safety net in times of stress. This is predominantly true in far-off rural settlements of Botswana, in spite of rapid socio-economic development (Sallu *et al.* 2009). However, considering the prevailing soil conditions, the vegetation cover over much of the Kalahari is surprising.

Despite the resultant mean moisture shortage and the lack of surface water, the Kalahari is a well-vegetated desert, partly due to the nature of the Kalahari Sand, which covers the surface and reaches thicknesses of more than 400 m in some places. Sand is not usually regarded as a good medium for plant growth, but in arid and semi-arid environments it can trap and retain moisture from short rainfall events (Thomas & Shaw 1991). Therefore, vegetation growth is possible and plants and animals have evolved wonderful ways of coping with the heat and harshness of the Kalahari, but the low nutrient status of the Kalahari Sand does not favour attempts to cultivate it.

HUMAN HISTORY

Even though the Kalahari environment limits human life, we have had a long association with the area, probably going back as far as the early hominids. *Australopithecus africanus*, first discovered at Taung in the North-West province of South Africa, is a good example. Taung lies on the southern fringes of the Kalahari. This environment has been occupied by scattered human groups until recent decades. These groups practised lifestyles well adapted to the harsh conditions and coexisted with the substantial variety of indigenous wildlife. Archaeological evidence indicates human occupation from the Early Stone Age to the present day and within this time span, societies have changed from a hunter-gatherer existence to pastoralism, agriculture and multiple land use, exhibiting increasing degrees of technological complexity within each stage. The Late Stone Age has been viewed as a culture personified by the San, who continued to live a forager lifestyle in isolation from Bantu-speaking people, until as recently as 200 years ago (Thomas and Shaw 1991).

Cattle and ceramics were introduced into the Kalahari about 2000 years ago in conjunction with pastoralist cultures, while the development of metallurgy, grain cultivation and transcontinental trade started in the area around 800 AD. In the early 1900's science generally underwrote the cattle industry, but finally in 1971 concern was expressed about environmental degradation (Thomas and Shaw 1991).

The Kalahari Desert is notable for its lack of permanent, and even seasonal, water courses and for the people residing in the semi-arid climate of southwest Africa, in particular, water scarcity provides a major stumbling block to increasing communal and individual well-being. One of the major water resources in this region is the Okavango River system.

THE OKAVANGO RIVER SYSTEM

Spanning three countries, the Okavango River starts its journey in the highlands of subtropical, central Angola, after which it enters the Caprivi Strip of Namibia, where it flows as a single river, before spreading its water across the "lifeless" sands of the Kalahari in Botswana, creating a natural refuge and giant water-hole for the biodiversity of the region (Fig. 2.4). The Okavango is one of the largest rivers in southern Africa, yet it never reaches the sea, instead, thirstland meets wilderness in Botswana, giving rise to many forms of life unexpected in an arid environment such as the Kalahari.

According to Ross (2003), rivers that do not reach the sea are typically found in arid areas. It can be said that the Okavango River is a relatively underdeveloped hydrological system (Kniveton and Todd 2006) and is definitely one of the least developed river basins in Africa (Andersson *et al*. 2006). It is occupied by 14 major ethnic groups with different cultural backgrounds, including the San people, who are probably the most marginalized people in southern Africa, not only in terms of inadequate access to education, health and economic benefits, but also in terms of their cultural identity (Kgathi *et al*. 2006).

The Okavango River supports livelihoods in various ways, such as through tourism, water supply, irrigation and horticulture and potentially for energy supply (Kniveton and Todd 2006). It is a river of critical importance to the well-being of its people and animals in all three the basin states and in each of these riparian countries the river takes a different shape - from many tributaries in Angola, to a single river flowing through the Caprivi and finally a flooded delta in Botswana (Fig. 2.6).

ANGOLA: THE START OF A LONG JOURNEY

The Portuguese have a description for south-eastern Angola – *as terras do fim do Mundo* – the place at the end of the earth (Mendelsohn and El Obeid 2004). The Okavango River's entire catchment lies within this remote, wild country where most of the stream flow is generated. Angola is the part of the Okavango System where rainfall and, therefore, water is plentiful. Sadly, however, it is an area that has suffered the ravages of war and corruption and as a result is often called "the sleeping giant" (Andersson *et al*. 2006), in the sense that water resources there are relatively unexploited.

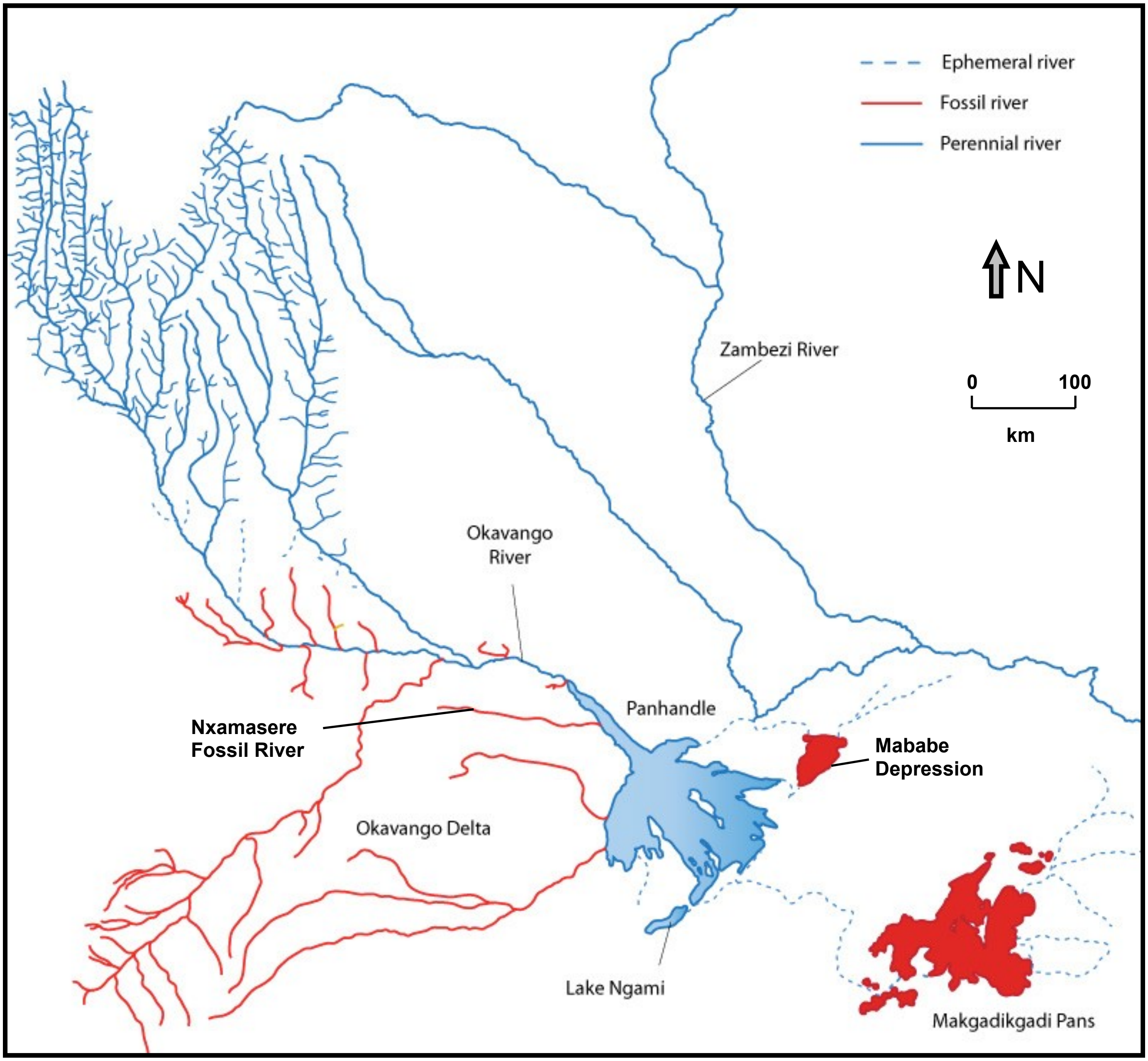


Figure 2.6: The Okavango River Basin. The Okavango River starts as many tributaries in the Angolan highlands, the two main tributaries being the Cuito and Cubango Rivers. These rivers join to form the Okavango River, which then flows through the Caprivi Strip of Namibia. On entering Botswana, the River enters the Panhandle, before dispersing over Kalahari Sands, forming an inland Delta. Fossil rivers (in red), which used to flow into the River and Delta, are also present (courtesy of the Aquatic Parasitology Research Group, UFS).

The Okavango River originates from a series of headwater streams on the southern slopes of the Angolan highlands, close to the Southern Equatorial Divide watershed, where mean annual rainfall is in the region of 1,300 to 1,400 mm (Thomas and Shaw 1991). The two main tributaries are the Cubango and Cuito Rivers or, as Thomas and Shaw (1991) put it, the Cubango River becomes the Okavango at its confluence with its major tributary, the Cuito. The many tributaries flow approximately 1,000 km through valleys which vary in width from 0.25 to 1.5 km (Kgathi *et al.* 2006). The Headwater basin of the Cubango/Okavango, taking the region north of the Middle Kalahari or north of Mohembo, is around 121,700 km^2 in size (Thomas and Shaw 1991), while the active part of the catchment that supplies almost all water to the river is wholly located in south central Angola and comprises approximately 112,000 km^2 (Kgathi *et al.* 2006). This active part is largely unpopulated partly because of the war and partly because the area is quite remote. Neither the swamps, nor the sandy terraces of the two main tributaries are currently extensively used for agriculture and present day clearing is slow. It is, however, taking place, often cautiously, around larger, more permanent towns and villages as more widespread resettlement is restricted by the presence of landmines (Kgathi *et al.* 2006).

THE OKAVANGO AS A SINGLE RIVER THROUGH NAMIBIA

After Angola, the Cubango River marks the border between northern Namibia and Angola for hundreds of kilometres and it is along this stretch that the Cuito joins it to form the Okavango River. After marking the border for nearly 400 km on an almost due east course, the Okavango River enters the Caprivi Strip of Namibia and a 40 km section of rapids, where it flows as a single river in a south-easterly direction towards Botswana. According to Thomas and Shaw (1991), the southern end of this part of the river is in a valley that is more than 3 km wide and is cut into the Kalahari Plateau by approximately 15 m. This section of the river is also marked by a quartzite ridge that ponds back the water to form a channel 300 m wide. The ridge is topped to form a series of rapids, with a height of more or less 5 m. These rapids are known as the Popa Falls (Fig. 2.10A & Fig 2.10B).

In Namibia, the southern bank of the river is densely populated, due to the overall scarcity of water in the country, while in Angola the Cubango and Cuito rivers and related tributaries occur in a country with relatively high rainfall. This contrasts with the situation in Namibia, where the mid-Okavango forms a unique, narrow wetland strip in one of the driest countries in the region (Kgathi *et al.* 2006).

FLOODED DESERT IN BOTSWANA

After flowing through the Caprivi Strip, the Okavango River enters Botswana at the town of Mohembo. On entering Botswana, the Okavango River forms a delta which is, according to Kniveton and Todd (2006), geomorphologically speaking, an alluvial fan formed where the river terminates. When the Okavango River enters Botswana, it is approximately 200 m wide and 4 m deep. Here, in the upper reaches in Botswana, the river is confined within a depression or broad floodplain, known as the Panhandle, before dispersing over the alluvial fan.

The entire flow of the Okavango River is confined to the main channel before it is guided into the Panhandle between two northern faults about 15 km apart. Immediately downstream of Mohembo, the Panhandle zone broadens out, water spilling and flooding the land between the faults, causing the main channel to be flanked by increasingly wider zones of permanent swamp that are fringed on the outer edges by narrow areas of seasonal swamp. This feature extends all the way south to the Gumare Fault, where the water disperses over the alluvial fan, such that, on a map, the Panhandle looks like a northern “wrist” and the Delta Fan like a many-fingered “hand” (Fig. 2.7) (Mendelsohn and El Obeid 2004; Ross 2003).

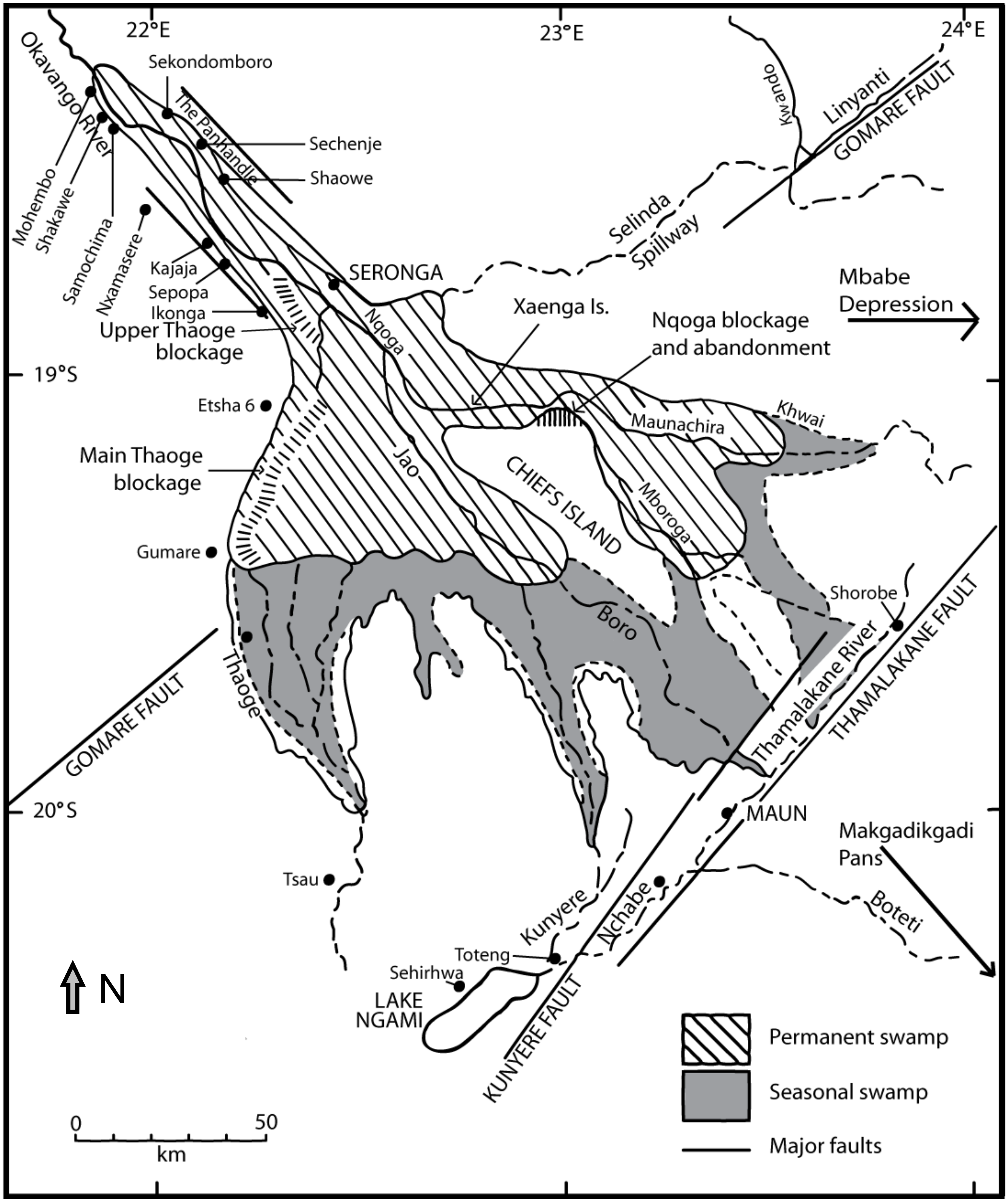


Figure 2.7: Main features of the Okavango Delta, including: faults controlling its shape, main channels, the rivers via which outflow leaves the Delta as well as Lake Ngami. Towns situated along the Panhandle and elsewhere are also indicated (redrawn from Thomas & Shaw 1991).

FAULTS IN THE LANDSCAPE

The entire Delta's shape is controlled by a series of faults, which, according to Ross (2003), are a continuation of the Great Rift Valley of East Africa. Two parallel faults control the direction in which the Okavango River enters the Delta from the north-west, in the area known as the Panhandle. These faults are at right angles to the main structural trend and probably also control the orientation of the Panhandle (Thomas and Shaw 1991). Other faults direct the river's exit to the south. As the Okavango flows over the Gumare Fault at the southern tip of the Panhandle, the slope of the land breaks the river up into smaller channels that spread across the Kalahari sand. The Delta is restricted suddenly along its distal margin by two northeast-southwest trending faults – the Kunyere and Thamalakane Faults – which redirect the Delta's myriad channels (Fig. 2.7) (Ross 2003; Thomas and Shaw 1991). Very recent tectonic activity has also been implicated in hydrological shifts in the Okavango Delta, within the past century (Thomas and Shaw 1991). The faults are seismically active and the southernmost ones appear to be extending at a rate of approximately 2 mm/year (Kgathi *et al.* 2006).

As mentioned previously, these faults are an extension of the East African Rift System (Fig. 2.5) and the Okavango Delta, the way it is today, owes its shape and position to the faults controlling it, but:

- Has it always been this way?
- What is causing the rifting of eastern Africa and subsequent faulting?
- What does the Okavango's geological history look like and how did this astonishing river end up spilling over sand in the centre of a desert instead of flowing into the ocean?

GEOLOGICAL HISTORY AND SHAPING OF THE OKAVANGO

The tectonic framework of southern Africa, after the division of Gondwanaland, had a major impact upon the development of river systems within the subcontinent. A twofold system developed, whereby relatively short rivers with steep gradients drained from the Great Escarpment to the coast (an exoreic system), while longer, but lower gradient endoreic rivers drained from the opposite side of the escarpment into the interior Kalahari basin (Thomas and Shaw 1991).

Shortly after the break-up of Gondwanaland, a drainage network involving three major river systems, had established itself in the interior of southern Africa (McCarthy and Rubidge 2005). Geological evidence suggests that long ago, during the late Pliocene – early Pleistocene period, the Okavango River along with the Chobe, Kwando and Upper Zambezi Rivers flowed south-eastward as one enormous river across the central Kalahari, joining the Limpopo River and flowing onwards to the Indian Ocean (Fig. 2.8A) (Kgathi *et al.* 2006; Ross 2003). This massive river is known as the Limpopo River, the most extensive of the three historic interior systems, which drained the vast northern regions of southern Africa. Sediment eroded from this huge catchment and was deposited at the river mouth, where it formed a massive delta on the Mozambique coast. Today, this delta forms the arc-shaped coastline between Maputo and Beira (McCarthy and Rubidge 2005). The Lower Zambezi River, on its own, formed the Zambezi System (Kgathi *et al*. 2006) on the east coast of southern Africa, but was not one of the three major interior rivers (Fig. 2.8A).

The second of the major rivers was the Karoo River, which drained the eastern highlands and flowed to the west, while the third, the Kalahari River, drained the western interior, also flowing to the west. The escarpment itself was drained by a number of short rivers which, today, is still evident along the KwaZulu-Natal and Cape coasts (Fig. 2.8A) (McCarthy and Rubidge 2005).

About 60 million years ago, gentle arches (called 'axes') began to form in the interior of the African continent, two, of which, had particular importance for southern Africa. They resulted in the Kalahari Basin being formed. Earth movements created the Transvaal-Griqualand Axis, resulting in the Karoo River capturing the Kalahari River and forming the modern Orange River system (Fig. 2.8B) (McCarthy and Rubidge 2005; Ross 2003).

The uplift of the Kalahari-Zimbabwe Axis rift cut off the headwaters of the Limpopo, obstructing its flow and causing the damming back of the giant river. As a result, a series of huge and complex swamps or lakes began to form behind the ridge in the interior, notably Lake Makgadikgadi, the largest of these lakes and the ancestor of the present Makgadikgadi Pans. Lake Makgadikgadi was a body of water much like Lake Victoria is today (Fig. 2.8B) (McCarthy and Rubidge 2005).

According to Thomas and Shaw (1991), there is sufficient data available on the geomorphology of the Okavango and its associated rivers and basins to indicate these changes. Evidently, periods of extensive lakes were interspersed with periods of Aeolian activity in the basins and geomorphological evidence indicates that there were two major palaeo-lake stages.

Three fault-controlled sedimentary basins, closely associated to the Okavango, lie at the distal end of the Delta. These now independent basins are the Mababe Depression, which lies to the north-east, the Makgadikgadi Pans to the southeast and in the south-west, Lake Ngami (Figs. 2.6 & 2.7). Of the two major palaeo-lake stages mentioned above, Thomas and Shaw (1991) state that Lake Palaeo-Makgadikgadi was the higher at the 940 to 945 m level and represents the fossil lake at its greatest extent. It covered all three basins (Ngami, Mababe and Makgadikgadi) and the lower part of the Okavango Delta, estimates of its size varying from 60,000 km^2 to 80,000 km^2.

A second stage can be recognized by linking the 936 m landforms in the Ngami and Mababe Basins along the Thamalakane Fault, with extensions to Lake Caprivi. This lake stage was termed Lake Thamalakane (which was probably controlled by a number of thresholds at the 936 m level, including the thalweg of the Thamalakane River) and most likely had an area of about 7,000 km^2 in the region of the Delta. It would, however, have overflowed to the Makgadikgadi Basin, supplying either the 920 m or the 912 m level. Below this level, Lake Thamalakane would have split to its constituent basins, each with their own responses to climate and hydrology (Thomas and Shaw 1991).

By about 20 million years ago, the East African Rift system was beginning to spread into southern Africa, influencing particularly the Zambezi River system. At about this time the interior of southern Africa began to rise. This uplift of southern Africa over the last 20 million years is unusual and has, in fact, resulted in a topographic abnormality of global significance. Areas of similar geology and geological history, elsewhere on Earth, lie at elevations of around 300 and 400 m above sea level, while most of southern Africa lies at elevations over 1,000 m above sea level. This topographic irregularity – the African Super Swell – has recently become the focus of intense research (McCarthy and Rubidge 2005).

Plate Tectonics explains most of the topographic features on earth, such as the Himalayan Mountains, but the African Super Swell poses a problem, as it lies far from any tectonic plate boundaries, where most other topographic features occur. To investigate this feature, earth scientists have been using seismic tomography, in which seismic waves from distant earthquakes are recorded by sensitive seismometers (McCarthy and Rubidge 2005).

It turns out that there is a massive ‘blob of hot material’ lying deep in the mantle, beneath southern Africa. This splodge is nearly 2,000 km in diameter and appears to be rising towards the surface like a rising bubble in thick syrup.

Consequently, the earth's surface is being pushed up, creating this Super Swell. The blob has a tail, much like that of a giant tadpole. The tail lies in the region of the East African Rift Valley and is undoubtedly responsible for the rifting in that region. It is possible that, some time in the future, the blob will reveal itself by major rifting of southern Africa as it nears the top of the mantle (McCarthy and Rubidge 2005).

Approximately 20 million years ago, when the uplifting of southern Africa started, the eastern portion of the continent rose more than the west. There were two main periods of uplift. The first, which took place about 20 million years ago, caused the east to rise by about 250 m and the west by about 150 m. The second (approximately five million years ago) raised the east by 900 m and the west by only 100m. The increased height of the eastern escarpment reduced rainfall in the interior, as moist air from the Indian Ocean lost more of its water as it rose against the escarpment. This increased the east to west rainfall gradient even more (McCarthy and Rubidge 2005).

The upwelling of cold water began on the west coast about 14 million years ago and caused extremely arid conditions to develop in the west. Lakes in the Kalahari basin began to dry up. The Zambezi River progressively captured the major tributaries of the lakes, intensifying the drying of the lakes and, finally, the lake and river deposits in the Kalahari basin gave way to desert sand (Fig. 2.9A) (McCarthy and Rubidge 2005).

The East African Rift system continues to propagate into southern Africa and has led to the faulting described previously. The faulting has led to the diversion of the Kwando River into the Zambezi River and the Lower Zambezi has since captured the Upper Zambezi. The Okavango River, on the other hand, entered the flatness of the Kalahari, where it slowed and deposited its sediment load, forming the Okavango Delta in northern Botswana (Fig. 2.9B) (Kgathi *et al.* 2006;

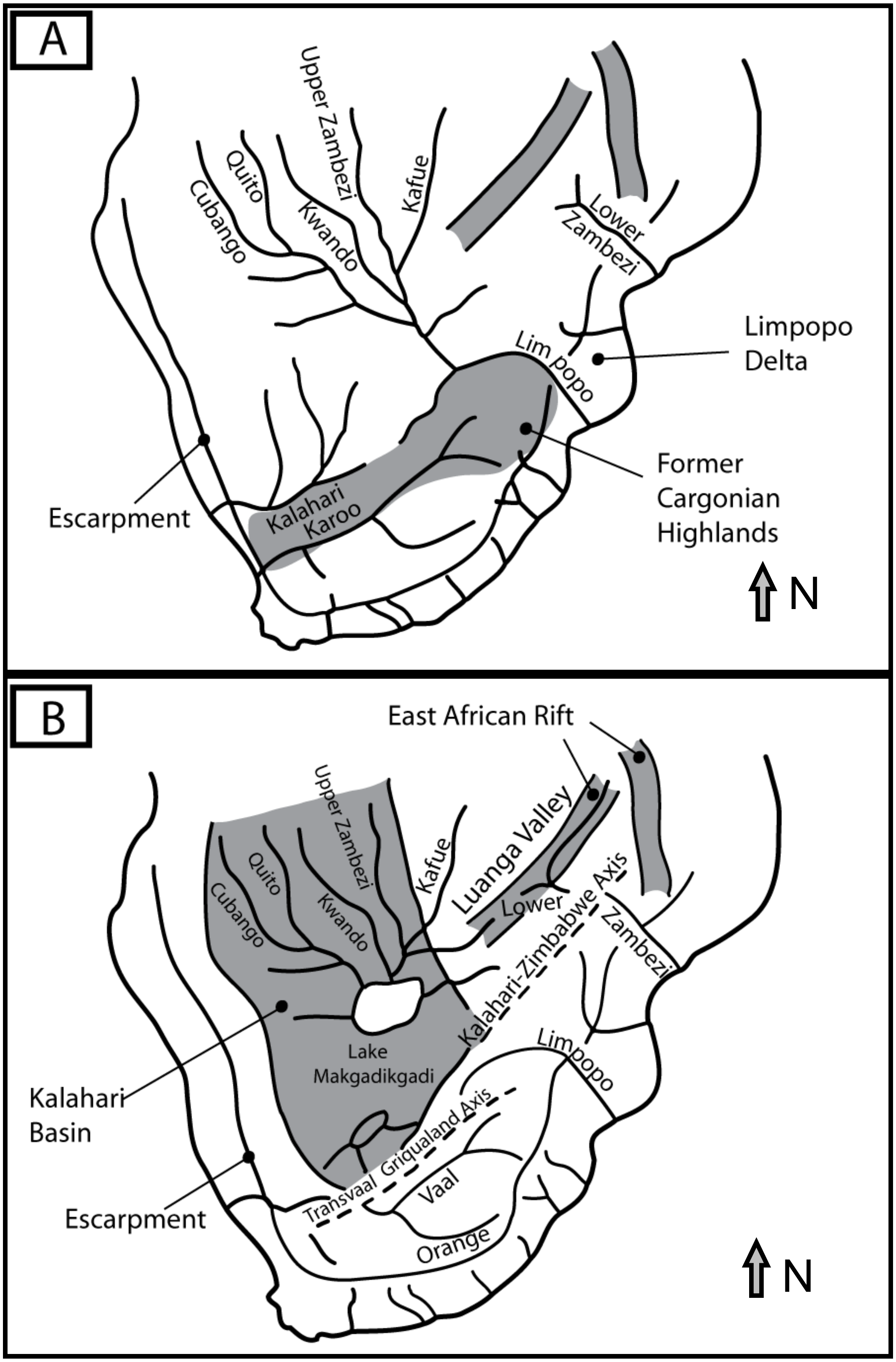


Figure 2.8: (A) The three major river systems of southern Africa, the Kalahari, Karoo and Limpopo Rivers, shortly after the division of Gondwanaland. **(B)** The two axes which caused the formation of the Orange River and the damming back of the Limpopo River, forming Lake Makgadikgadi (redrawn from McCarthy & Rubidge 2005).

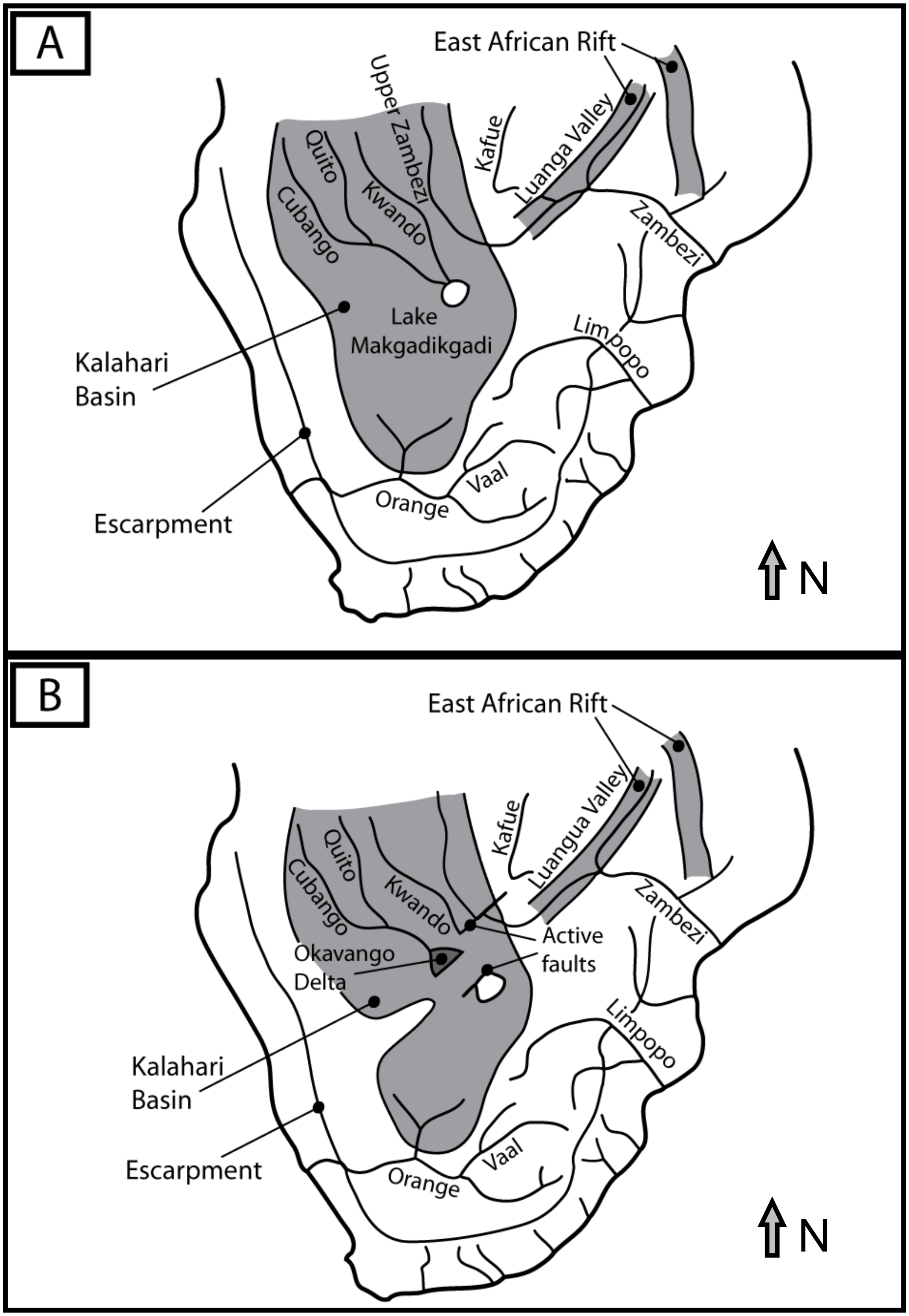


Figure 2.9: (A) The Zambezi River captured some of the tributaries of Lake Makgadikgadi, intensifying the dryness of the Lake. **(B)** Faulting led to the Kwando diverting into the Zambezi River and the Lower Zambezi capturing the Upper Zambezi. The Okavango River entered the Kalahari and formed the Okavango Delta (redrawn from McCarthy & Rubidge 2005).

McCarthy and Rubidge 2005; Ross 2003). According to Ross (2003), channels became blocked and water followed other courses, continuing to deposit sediments wherever it flowed and, over time, about two million tons of sand and debris were deposited. This created the Delta's characteristic fan shape as we know it – an alluvial fan which is the last surviving relic of the great Lake Makgadikgadi.

CURRENT SHAPE OF THE OKAVANGO OASIS

Today, most of the Okavango Delta's water flow, in the upper reaches, is along a single channel, which meanders widely down the length of the Panhandle (Fig. 2.10C). The meandering of the river means that erosion takes place on the concave banks of the meander bends (cut banks) (Fig. 2.10D), while deposition of sediment takes place on the convex banks of the meander bends (Fig. 2.10E). As a result of the combination of erosion and deposition, the channel gradually migrates across the floodplain and such migration may lead to the formation of oxbow lagoons that are isolated from the main channel (Fig.2.10F). These old oxbow lagoons are evidence of the extent of the meanders and have been separated from the present channel, now remaining as isolated lagoons of varying sizes (such as Guma Lagoon and the lagoons around Duba Island). Several of these oxbow lagoons are still linked with the main channel by narrow channels, though they receive water primarily as "underflows" from the fringing swamp areas and not as direct inflows from the main channel (Alonso and Nordin 2003). A good example of a lagoon linked to the main channel by a narrow channel is Samochima Lagoon in the Upper Panhandle (Fig. 2.11A & B). Sometimes the river swings past a mainland spit which's edges are lined by dense riparian forests (Fig. 2.11C). In the Upper Panhandle, vegetation distribution is entirely a product of the fluvial processes of erosion and deposition.

The Panhandle is about a 100 km long, perennially flooded area of marshes, dominated by papyrus and reeds (Mendelsohn and El Obeid 2004). Although the

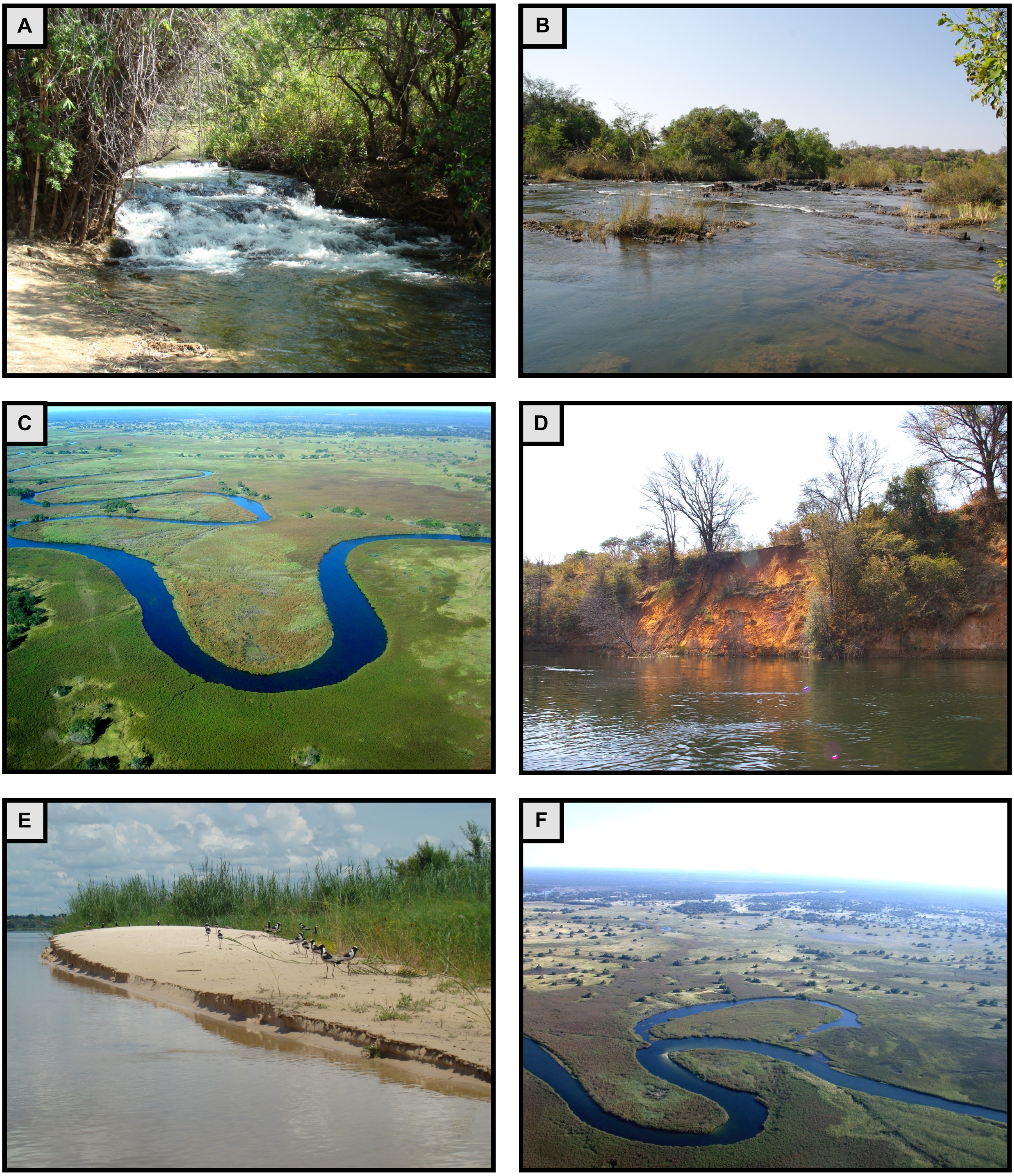


Figure 2.10: (A) & (B) Rapids at Popa Falls in Namibia's Caprivi Strip. **(C)** The Okavango River meandering down the length of the Panhandle. **(D)** An eroded concave bank of a meander bend at Red Cliffs. **(E)** Sediment deposited on the convex bank of a meander bend. **(F)** An oxbow lagoon beside the main channel in the Panhandle. **(C), (D) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

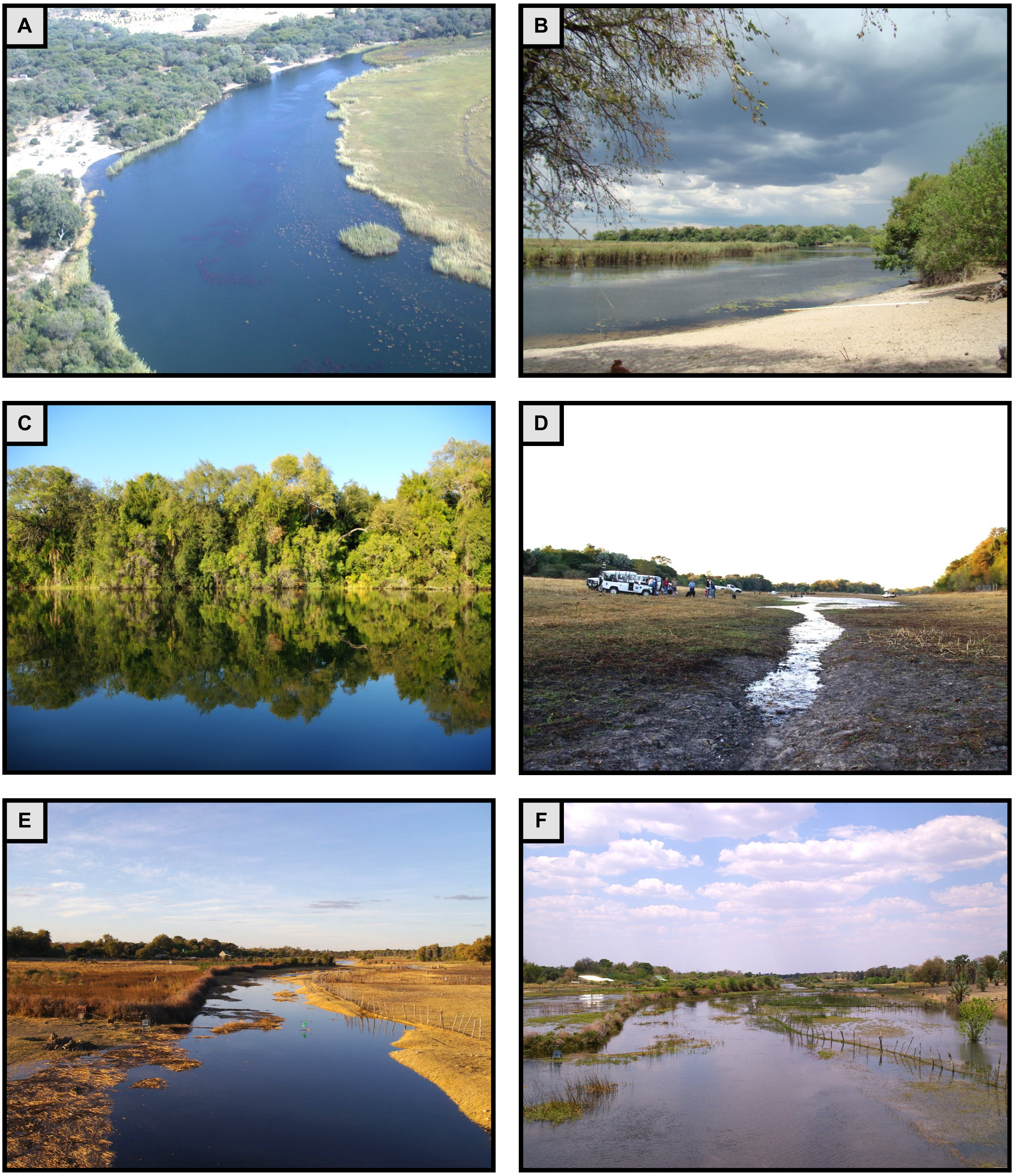


Figure 2.11 (A) Samochima Lagoon: an oxbow lagoon which is linked to the main channel by a narrow channel. **(B)** Samochima Lagoon borders the mainland. **(C)** Dense riparian forest at the edge of the mainland at Samochima Lagoon. **(D)** Water arriving at Maun in the midst of the dry season. **(E) & (F)** Different levels of water flowing through the Thamalakane Bridge in Maun in different years. **(A), (D), (E) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

Panhandle is about 100 km long, the Okavango River flowing down the Panhandle is more or less 300 km long. This is due to the meandering of the river over this flat terrain. The river in the Panhandle flows strong enough to hold back plant growth and papyrus bends passively over its banks. A few kilometres downstream of Mohembo, near Shakawe (Fig. 2.7), the main channel carries approximately one-quarter to one-third of the water that flows down this zone of the Delta, while the balance of the water travels through the papyrus and swamp areas, becoming “filtered” in the process. Water flow rates are high, up to 0.9 m/sec, in the main channel, from which the water flows sideways and outwards into and through the perennial swamps of this zone. Here, water flow rates amongst the flooded grasses and reeds are usually below 0.1 m/sec (Alonso and Nordin 2003). These huge stretches of reedbeds act as a filter, slowing the water so that the sediments are deposited (Ross 2003). Overall, it is this continual flow of water that shapes and forms the perennial swamps and “drives” these ecosystem components and their associated ecological processes.

Between the Upper and the Lower Panhandle, the Okavango River becomes noticeably narrower with increasing distance down the Panhandle and throughout its length the main channel is fringed by dense permanent swamp (Fig. 2.10C & F). The permanent swamp grades gradually into more seasonal swamp vegetation with increasing distance from the main channel. This meandering journey through the Panhandle is the Okavango’s last as a single river.

When the Okavango River reaches the southernmost part of the Panhandle at Seronga, it is met by the Gumare fault, or a depression in the Kalahari sands, which causes the river to spread out into several tributaries creating a mosaic of water and land (Fig 2.7). These are the “fingers” of the “hand”. According to Thomas and Shaw (1991), the Delta has five ‘limbs’ of distributaries, which flow through seasonally or occasionally flooded floodplains. These, from east to west, are the Selinda, Maunachira, Mboroga, Jao and Thaoge distributaries (Fig. 2.7).

Some travel south, while others flow east, only to be met by a fault line in the landscape which directs them southwards again. These main channels carry the bulk of the Okavango's water through the Delta and serve as an arterial system supplying water to permanent and seasonal swamps. Therefore, primary water distribution within the Okavango Delta occurs via the channels and secondary water distribution occurs mainly via overland flow through vegetated swamp. The channels are between 20 and 30 m wide and up to five metres deep and are mostly devoid of vegetation because of the flowing water (Alonso and Nordin 2003; Ross 2003).

Apart from the main channels, the water seems to spread over the flat Kalahari Sands almost aimlessly. Some channels lead to hidden lagoons (which may reach a depth of several metres), while others are lost in a network of thick reeds. However, all the waters are, in truth, connected as they pass through reedbeds on their journey south (Ross 2003). Upstream sections and areas close to the main channels tend to have water permanently, while the downstream sections and areas farther from the main channels tend to be seasonally flooded (Pendleton and Baldwin 2007).

RAINS

In Botswana, the lower Okavango River, and subsequent Delta, contrast sharply with the surrounding land, where rainfall is low and erratic, evaporation rates are high and surface water is absent for most of the year (Kgathi *et al.* 2006). Here, rainfall is in the region of 500 mm/year and potential evaporation is five to six times that of the rainfall (Garstang *et al*. 1998; Alonso and Nordin 2003). The rains fall mainly in the summer months, from November to March, but the pattern changes time and again. In some years there is little or almost no rain and drought sets in (Ross 2003). In contrast to the rainfall, evaporation is higher in winter months.

Pula means “rain” in Botswana and is also the name of the country’s currency, while *Thebe* (the word for small change in Botswana) means “small droplets”. This indicates the value placed on rain, which comes as a dramatic, long-awaited event.

The build-up to rain lasts for months. Large continental air masses bring high atmospheric pressure with them and immense cumulus clouds and isolated showers are typical of the Delta’s rains (Ross 2003). The heavy atmosphere builds slowly, winds start to blow and the air becomes hotter than usual. Lightning and thunder are characteristic of the rains. The rains cool the air down, but before long, it is hot again.

The Delta has more rain than other parts of the Kalahari at all times. Its water and vegetation undoubtedly create their own local climate, a lot like tropical forests do and the rain raises the water level. Although this local precipitation provides a third of the Delta’s water, about 96 % of its water is lost through evaporation and transpiration. So where does most of the water in the Delta come from? The local rain’s impact is little when compared to that of another rain-born event – the annual floods (Ross 2003).

ANNUAL PULSE FLOODING

In the highlands of Angola, the catchment area of the Okavango, rains fall mainly between October and April. In the Okavango River, rainfall decreases from the higher altitude northern part of the catchment over Angola to the lower altitude Delta in Botswana. The annual rainfall in the catchment is about three times higher than that at the Delta and provides the further two-thirds of the Delta’s water. There are, thus, two distinct inputs to the regime. It is also stated that, overall, the Angolan portion of the Okavango catchment contributes approximately 94.5 % of the total runoff in the Okavango River, whilst about 2.9 % originates in Namibia and the other 2.6 % is provided by Botswana (Mendelsohn and El Obeid 2004; Thomas and Shaw 1991).

Within the huge catchment, rainwater collects, travels down the Cuito and Cubango Rivers and finally enters the Okavango, swelling the river's banks and producing a flood tide of water that travels southwards to the Delta. Although the rains in the catchment fall between October and March, the flood peak passes Mohembo, where it enters the panhandle, in April. As the flood travels down the river, its banks overflow, engulfing the land and covering the sandbanks. Fresh water flushes the papyrus swamps of the Panhandle, bringing remarkable change (Garstang *et al*. 1998; Ross 2003; Thomas and Shaw 1991).

On reaching the Delta Fan, the water spreads, flowing over river banks between thickets of reeds and papyrus, covering floodplains and slowly lifting the water level in lagoons and floodplains. The floods move slowly, travelling at a pace that does not often exceed a kilometre a day. This is partly because of the flatness of the landscape and partly because the water is slowed by swamp vegetation. At this speed, the floods take more or less four to five months to travel the length of the Delta (250 km), from the start of the Panhandle, reaching its southern-most end in July and replenishing life in these drier parts in the midst of the dry season (Fig. 2.11D). Therefore, the maximum aerial extent of flooding is from July to August. At the time of flooding, much of southern Africa south of 15°S, particularly regions to the west and south of the Okavango, have been without any considerable rain for four months (Garstang *et al*. 1998; Ross 2003).

The Okavango River has a mean annual discharge of approximately 9.86 km^3, while the Delta receives an average of 15.5 km^3 of water annually (Alonso and Nordin 2003; Thomas and Shaw 1991), of which two-thirds is from inflow initiating from the Angolan highlands, with the remainder of the precipitation over the Delta itself. The precise pattern of flooding each year is dependent on previous conditions, such as the degree and duration of previous floods. It is also dependent on the timing and extent of rainfall in the catchment and direct rainfall onto the Okavango Delta and, therefore, is never the same for two successive years, as indicated by flood data collected at Mohembo (Fig. 2.12A & B). In turn, the flooding pattern determines the spatial and temporal extent of the different ecosystem components within the Okavango Delta (Table 2.4) (Alonso and Nordin 2003).

Table 2.4: The different ecosystem components within the Okavango Delta and the average area covered by each of these components (compiled from Alonso & Nordin 2003).

Ecosystem Components	**Average Area**	
	km²	**%**
Perennially flooded swamp	4,885	30.8
Regularly seasonal flooding (once per year)	3,855	24.4
Occasional seasonal flooding (once every three to five years)	2,760	17.4
High floods only (once every ten years)	2,502	15.8
Dry land (islands which are never flooded)	1,842	11.6
Total area of Okavango Delta	**15,844**	

In recent years, low rainfall in Angola has led to low water levels and near drought conditions in the Delta, while more recently (1998 - present), rainfall and water levels have increased, though these are still below long-term average levels (Alonso and Nordin 2003). The total volume of water entering the Delta varies from year to year, but some 96 % is lost to evapotranspiration or ground water, while the remainder leaves as outflow from the distributaries (Thomas and Shaw 1991). The changes in flood level from year to year can be demonstrated

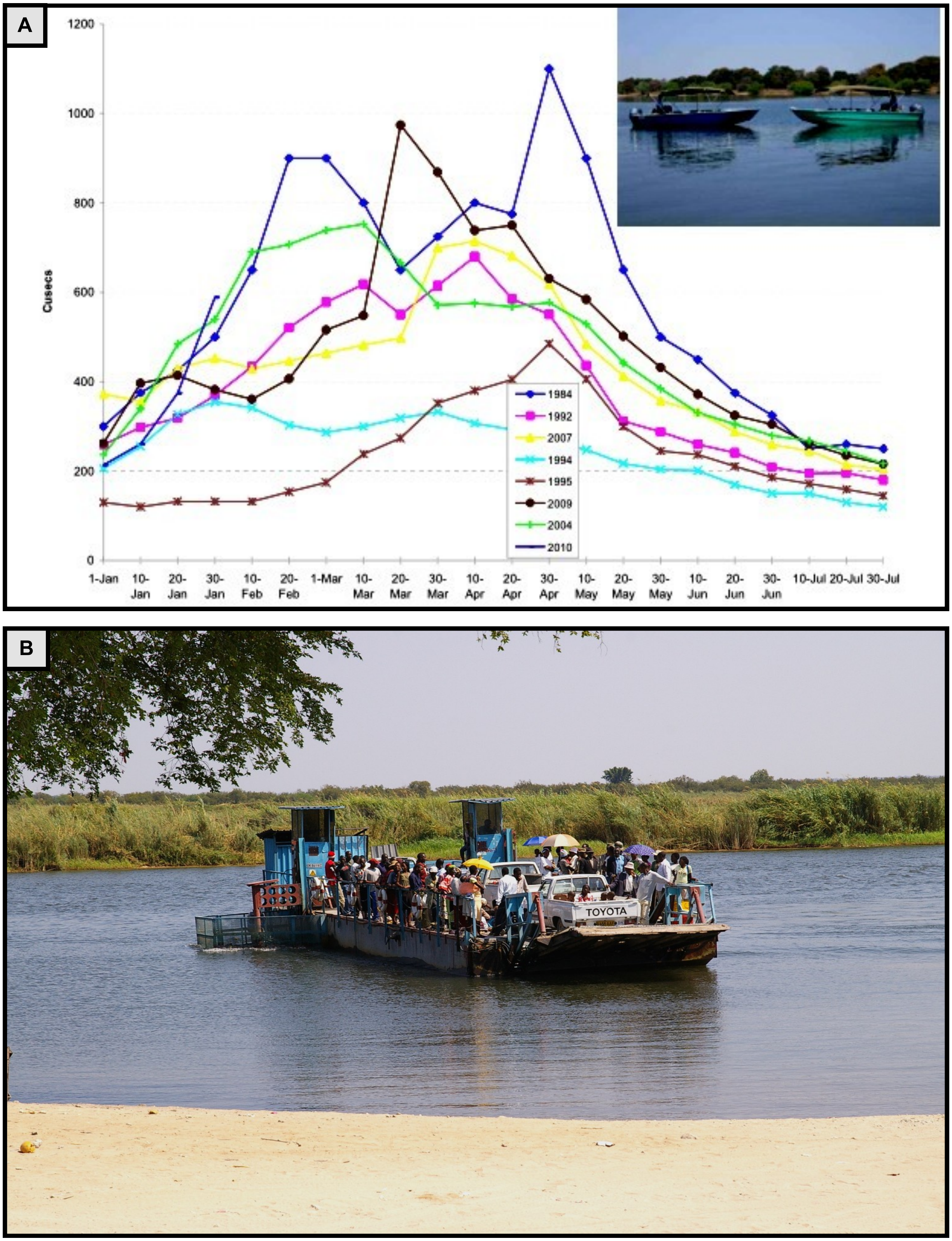


Figure 2.12: (A) Levels of flooding in the Okavango Delta during different years (Data collected at Mohembo) (graph obtained from Aliboats, Maun, Botswana). **(B)** The ferry at Mohembo transporting people and vehicles to the eastern bank of the Okavango River (courtesy of the Aquatic Parasitology Research Group, UFS).

by the volume of water flowing through the Thamalakane Bridge in Maun each year (Figs. 2.11E & F).

After a journey that has taken several months, the water being sucked up by arid sands, drawn up by the sun and used by countless people, plants and animals, the last of the Okavango's waters are lost in the shallow floodplains of the Lower Delta. The journey does not quite end here.

According to Alonso and Nordin (2003), a variety of estimates have been offered for the quantities of water that are lost each year from the Okavango Delta via evapotranspiration, seepage to local ground water and outflows to the Thamalakane River. Only between 1.5 % and 2 % of the inflow into the Delta leaves it as outflow (Garstang *et al*. 1998; Kgathi *et al.* 2006). The five 'limbs' of distributaries all drain in the direction of other water bodies closely associated with the Okavango System. According to Thomas and Shaw (1991), the most easterly distributary of the Delta, the Magwegqana or Selinda Spillway, occasionally carries water to the adjacent Linyanti River, and hence toward the Zambezi. The Maunachira system drains towards the Mababe Basin, east of the Delta, while the most westerly distributary, the Thaoge, drains towards Lake Ngami, which lies at the south-western tip of the Delta. The central distributaries, the Mboroga and Jao, are terminated by the distal Kunyere and Thamalakane Faults, which again distribute water towards the Ngami and Mababe Basins via the Kunyere River and the two-directional Thamalakane River, with an additional offtake via the Boteti River towards the Makgadikgadi Basin (Figs. 2.6 & 2.7).

THE MABABE DEPRESSION

Following the Thamalakane River north-east from Maun, the thalweg reaches a maximum altitude of 936 m above sea level close to the village of Shorobe, then decreases towards the Mababe Depression. This suggests the possibility of bi-directional flow at times when water is abundant. The Thamalakane is joined by the Khwai River before it enters the Mababe Depression at its southern extremity (Fig. 2.7). Water from the Okavango can also enter the basin by a more indirect route via the Savuti channel. The Savuti is an offshoot of the Linyanti system and has a unsubstantiated connection to the Okavango via the Magwegqana (Selinda) Spillway (Fig. 2.7) (Thomas and Shaw 1991).

The Cuando River (Kwando River in Botswana) rises in Angola and flows across the neck of the Caprivi Strip, after which it forms the border between Namibia and Botswana, as it continues south-east. Presently, the Kwando terminates into the Linyanti River, which flows east and connects the Kwando to the seasonal Lake Liambezi. From this point, the river is called the Chobe, which is connected to the Zambezi River (Figs. 2.1 & 2.7).

In years when the Delta experiences good floods, water escapes east, along the normally dry Selinda Spillway, into the Linyanti Swamp, connecting the Okavango to the Zambezi Basin. In 2009, flooding in the Okavango Delta was so high that the Selinda Spillway linked up with the Linyanti Swamps, after 30 years of being disconnected. The Linyanti, as well as the Savuti, may get sufficient flow due to the influence of the high flood in the Selinda Spillway and may, therefore, enter the Mababe Depression.

During the last hundred years, the Mababe has received little inflow and as a result, has not contained a standing lake in human memory. However, oral tradition supports the existence of ‘Lake Mababe’ in the eighteenth century, which dried out in the earlier years of the twentieth century. The Mababe Depression, itself, is a heart-shaped basin of about 90 km x 50 km at its maximum dimensions and can be considered a twin of the Ngami Basin or Lake Ngami (Thomas and Shaw 1991).

THE MAKGADIKGADI PANS

When the lower channels and waterways of the Delta meet a barrier, the Thamalakane Fault, the waters turn abruptly and about 18 km south of Maun, the Thamalakane splits into the Nchabe and Boteti Rivers, which take with them the last of the Delta's water, only a fraction of which arrived in the Panhandle from Angola (Fig. 2.7). The Boteti River is the main inflow to the Makgadikgadi Basin, which lies about 100 km to the east (Fig. 2.6). Assisted by human interference, the Boteti presently carries the greater part of the Thamalakane ouflow, yet this volume, which averages approximately 0.3×10^9 m^3 per annum, is barely enough to reach the Makgadikgadi most years. Clearly a misfit, the Boteti itself, has a carrying capacity equal, at least, to the full Okavango flow (Thomas and Shaw 1991).

The Boteti River carries the Okavango's waters several hundred kilometres into the Kalahari, south-east of the Delta in a river valley too wide and deep to be made by such a meagre flow. This is a reminder of the size of the great river that used to flow into Lake Makgadikgadi. For millennia, the wildlife of the region retreated to the Boteti when drought prevailed and, still today, the animals that inhabit the Makgadikgadi pans (Figs. 2.13A & B) and the interior grasslands go to the Boteti in the dry season (Ross 2003).

A hundred years ago, David Livingstone wrote of hunting Sitatungas at Lake Xau. This is an indication of the impressive water body Lake Xau once was, when it was fed sufficiently by the Boteti. Xau now stands dry and barren, scattered by skeletons of animals that reached their traditional water point, just to find it dry and were too weak to go further. At times of very high flood, waters from the Okavango might reach the edges of the Makgadikgadi, before they are burnt off in the salt pans by the sun. However, the last of the Okavango's waters most often end in a muddy pool, between the wide banks of the Boteti (Ross 2003).

Other inputs to the Makgadikgadi Basin are small too, compared to the size of the basin. The Makgadikgadi Basin covers about 37,000 km^2 and is occupied by a series of pans, for example Sua Pan, which has an area of about 3,000 km^2, and the larger Ntwetwe Pan. Sua is the lowest of all the pans, with a sump level of 890 m above sea level and also offers the prospect of almost unlimited resources of salt deposits. A number of smaller pans lie to the west and south of Sua, including Lake Xau, which is sporadically flooded by the Boteti River (Thomas and Shaw 1991).

LAKE NGAMI

When flow from the distal sector of the Okavango Delta reaches the Thamalakane Fault line, the water flows south-west along the Thamalakane and Nchabe Rivers, losing a considerable proportion of the flow at the Boteti divergence. The Nchabe, in turn, joins the Kunyere River (which flows parallel to the fault line) at the village of Toteng (Fig. 2.13C). From Toteng, these two rivers pass as a single channel into the shallow Lake Ngami (Fig. 2.7) (Thomas and Shaw 1991).

During recent decades, outflow from the Okavango Delta declined and the patterns of flow changed, but in 2004, outflow into Lake Ngami via the Nchabe/Kunyere River reached a size it had not attained for several decades and the Lake was inundated again (Kgathi *et al*. 2006).

Before the 1880's, Lake Ngami was being fed from a different side and by a different channel. In the 1800's, the Thaoge Channel (the most westerly of the five main channels) was the major distributary channel of the Okavango Delta, and carried the bulk of the Okavango's flow as far as Lake Ngami (Fig. 2.7). When David Livingstone travelled to Lake Ngami in 1849, it was a vast feature (more or less 100 km in circumference), supplied with water via the Thaoge (Alonso and Nordin 2003; Ross 2003).

At the turn of the last century, there was a major shift in flow from the Thaoge River to the eastern Ngakha and Mboroga systems (Fig. 2.7). It was this change in flow that led to the drying of Lake Ngami and the western edge of the Okavango Delta. Lake Ngami began to dry in the 1870's, receiving water on an on-and-off basis, but was totally dry from the 1980's, until 2004, when water reached it again via the Nchabe/Kunyere River, due to an increase in rainfall in the Angolan highlands. Today, the Thaoge hardly ever flows more than one third of its original length and is a relative trickle. The swamps that used to surround the Thaoge became vast areas of peat, which, over the years burnt away, creating areas of extensive grasslands. The drying Thaoge may never reach the lake again (Ross 2003).

In the last two decades, there has been a change in flow eastwards and the Nqoga River is presently the primary distributary channel in the Okavango Delta, but it, too, is experiencing failure in its lower reaches. Water is increasingly being diverted into the Maunachira and Khiandiandavhu Rivers further to the north and more recently, the pattern of waterways around the south-west of Chief's Island (Fig. 2.7) has altered (Alonso and Nordin 2003; Ross 2003).

CHANGING CHANNELS

So dynamic are the Okavango's waterways, that small changes may take place in as little as a year; others are more gradual, but the channels of the Okavango Delta, which eventually feed its associated basins, are always changing and following new courses (Ross 2003).

The floods, which arrive in the Delta towards the end of the summer, flush out the backwater swamps, revitalising the waters and providing extra habitats for, amongst others, cichlid fingerlings, which have been raised in the shallow back-waters. In fact, the breeding and movements of many fish species are adapted to the floods. Floating 'peat mats' play an important part in the Delta's constantly changing waterways and their formation is largely due to organic matter and detritus brought down with the floods (Ross 2003).

As the flood passes through backwater lagoons, the water slows down, depositing its load of detritus. Together with the mass of decaying vegetation, at the bottom of the lagoon, the detritus forms a fibrous layer, which is the start of a peat mat. The fibrous layer gains form and bulk with the establishment of various aquatic plants such as water lilies, water chestnuts and bladderworts. In time several peat mats, which are used by many swamp creatures, join to create larger and larger areas. These areas are then colonised by miscanthus grass and finally result in widespread regions of peat bog (Ross 2003).

The grass clumps can grow large enough to block the flow of water in places and, in time, they dry out causing permanent beds of grass to develop where there used to be water. The leaves of the peat mats contain soil, which is colonised by dry land grass. This eventually forms floodplain grasslands. The transformation of peat is due to blazing underground fires, which are fed by natural gases. The Delta's smouldering peat fires are also caused by river channels filling with sediments and drying as the waters seek another course. The current drops its load of sand as it slows, raising the bed of the channel until its water runs elsewhere. The reed beds on either side of an abandoned channel grow on thick beds of peat. They dry out and set alight from methane gas deep within the peat. Papyrus may look impossible to burn, but, in actual fact, it is highly combustible due to its high phenol content. Their feathery tops crackle and pop as the flames, which are fuelled by hot air, race through the reed beds, until the fire reaches the edge, where it is extinguished by the water. The nutrients released by the fires promote grass growth on the newly formed floodplains (Ross 2003).

As can be seen with the Thaoge and the more eastern distributaries, even major channels in the Okavango can have a life of less than one hundred years (Thomas and Shaw 1991). When water is slowed by blockages of vegetation and is lost to newly formed drainage systems, the death of a watercourse can occur. Free-floating islands of papyrus (which grows extremely fast) also play a role. Before long, a small ‘plug’ of vegetation can grow to cover a large dam (Ross 2003).

Elephant activity, too, can change the pattern of water flow as towards the end of the dry season, they wade into lagoons, churning up reeds as they look for succulent roots, especially in reed beds. Soon, the reed beds are flattened and new channels open for water to pass through. Chunks of reeds often float away and may, in turn, block other smaller channels. Hippos also play an important role (Ross 2003). Their constant movement from water to dry land is a major factor in creating and maintaining channels in the Delta, as they keep papyrus and peat mats from encroaching on their paths. Water seepage into swamp areas, away from the main channels, is accelerated by hippo trails. Once the bed of a main channel rises and water flow slows, as a result of sand deposition, the main flow may switch down a hippo trail. The now fast-flowing water can erode and widen the trail to form a completely new channel (Mendelsohn and El Obeid 2004).

The changing channels, elephants and hippo’s are not the only agents of change in the Okavango Swamps, as surface fires are common and three-quarters of the reed beds are burnt at some time during the year (Figs. 2.13D, E & F). These fires are often started by lightning from storms, but humans also play a role, as papyrus fires are more often started by hunters, hunting antelope. The antelope are attracted to the green shoots that grow after a fire and the hunters also wish to reduce the plant cover, so as to improve visibility (Ross 2003).

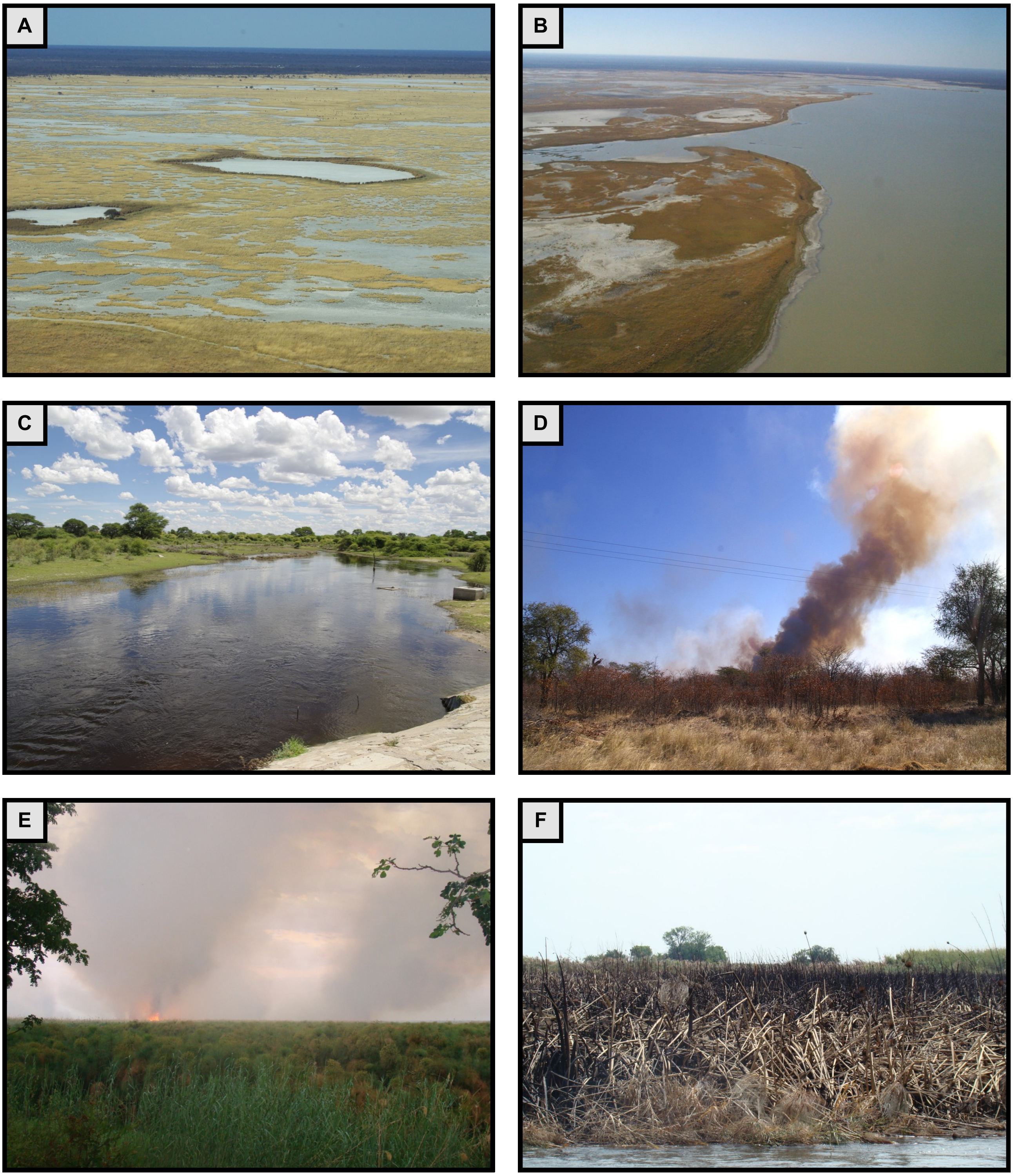


Figure 2.13: (A) & (B) The Makgadikgadi Pans. **(C)** The Kunyere River at the village of Toteng, where the Nchabe River joins it to flow into Lake Ngami. **(D)** Raging fire in the surrounding Kalahari bushveld, west of the Panhandle. **(E)** Papyrus burning in the distance. **(F)** Burnt papyrus next to the main channel, after a fire in the Panhandle. **(A), (B) & (D)** Courtesy of the Aquatic Parasitology Research Group, UFS.

The changing channels in this dynamic system play an important role in keeping the Delta's waters fresh. By having a limited life, as they quickly fill up with sand and change the direction of flow, they ensure that the Delta's ecosystems remain dynamic. The sediments, which cause rivers to be born and die quickly, create a variety of vegetation types and water channels, at different stages of development. The changing channels help to keep the Delta's water fresh, despite the heavy evaporation taking place. Evaporation of the water leaves behind deposits of earth salts which, normally, would accumulate to toxic levels, especially on sand islands, but instead are washed away by rain when a channel dries (Ross 2003).

Other than the changing channels, the Delta owes its fresh water to its rich plant life as well. Salts are concentrated on the Islands in the Delta. The trees growing on the islands transpire large volumes of water into the atmosphere, resulting in salts being concentrated on islands and, therefore, being removed from the Delta's waters. Salts become concentrated in most wetlands situated in hot and arid areas, for example the Makgadikgadi and Etosha Pans. The Okavango Delta is, therefore, an exception and its ability to remain fresh is remarkable (Mendelsohn and El Obeid 2004). Water in the Nxamasere floodplains (Figs. 2.14A - F), west of the Panhandle, is extremely salty, too, due to high evaporation rates, causing evaporite deposits to be left behind.

In the Makgadikgadi Pans, for example, water simply evaporates, leaving behind any salts it carried (Figs. 2.13A & B), while most of the water in the Delta is lost by transpiration rather than evaporation. As the plants draw up water into their roots, some salts remain in the plant, while the rest are left in the ground, from which they permeate into the groundwater below the Delta or become concentrated in the soils beneath the islands. The highest concentrations of salts are in the island centres (Mendelsohn and El Obeid 2004).

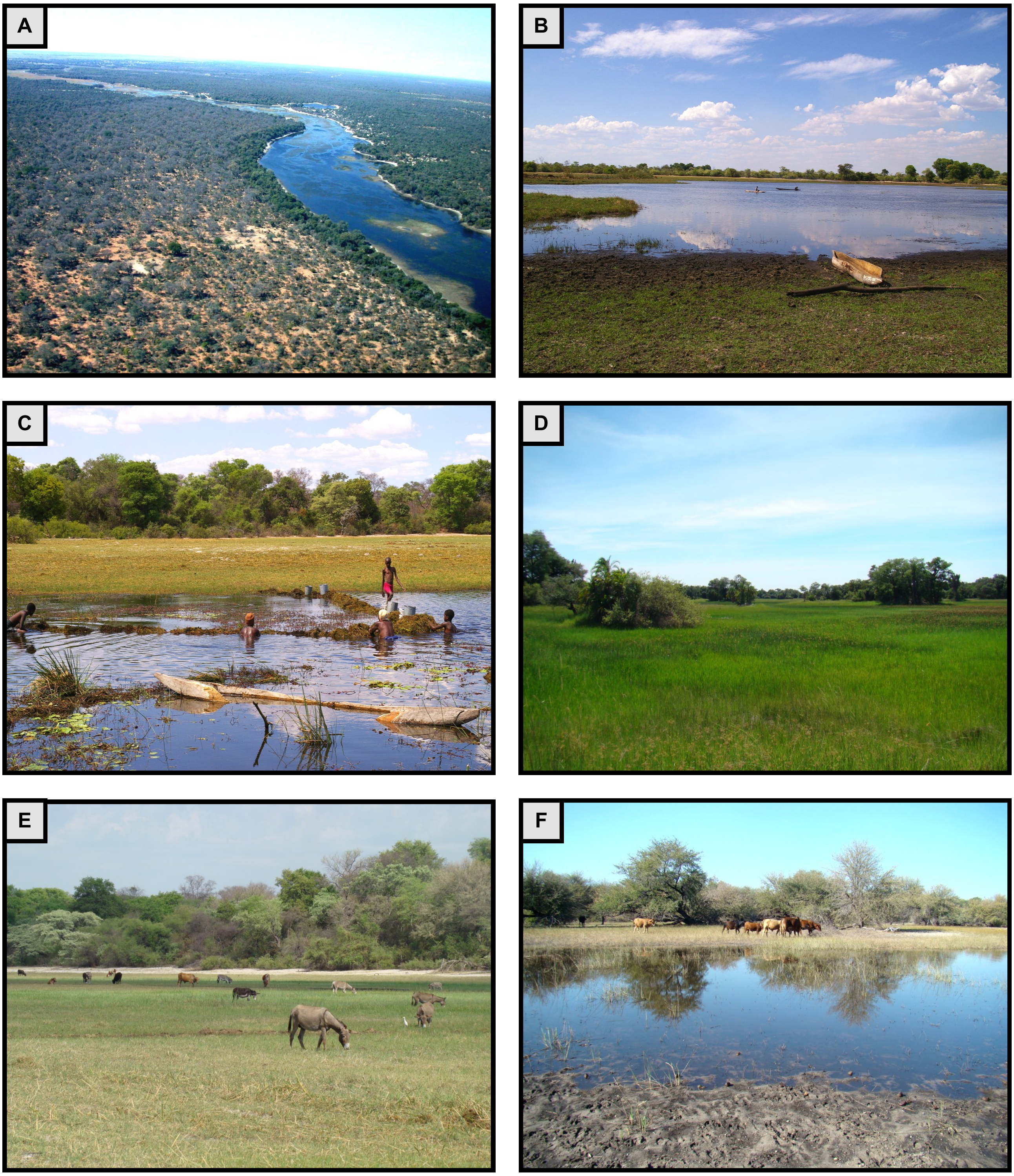


Figure 2.14: Nxamasere Fossil River and Floodplains. **(A)** Birds-eye view of the Nxamasere Channel. **(B)** One of the larger pools in the Nxamasere Floodplains. **(C)** Local women and children fishing in a pool for their next meal. **(D)** Nxamasere swamps. **(E)** Cattle and donkeys grazing in the riverbed. **(F)** A pool at Nxamasere, trampled by livestock. **(A), (B) & (C)** Courtesy of the Aquatic Parasitology Research Group, UFS.

The formation of these tree-bearing islands also changes the Delta's waterways. It is such changes to the spread of water that has lead to a fundamental characteristic of the Delta: the enormous diversity of habitats produced by the changing presence and depth of water across this oasis.

HABITAT DIVERSITY

The diversity of habitats in the Okavango Delta is remarkably high, a quality that results from a combination of changing channels, termites and hippopotomi activities and a pulsating flood regime. Although the Delta spills over an extremely flat terrain, which has a low gradient and is made up of homogeneous Kalahari Sand, it has large variations in vegetation patterns over small distances. Mendelsohn and El Obeid (2004) explain that small differences in elevation make large differences in the frequency and duration of flooding. This causes large variations in vegetation in a seemingly flat and homogeneous environment.

A mosaic-like vegetation pattern characterizes the entire Delta (including the Panhandle). This ranges from the riverine Panhandle to the fan-shaped Delta, with its number of river channels (both permanent and semi-permanent). The Delta is surrounded by backwater swamps. Permanent swamps surround the Okavango River meandering through the Panhandle, as well as the upper fan, while the outer edges of the entire Delta and the lower fan are characterized by seasonally flooded swamps. Found throughout the Delta, are oxbow lakes, some hidden and others interconnected by narrow waterways. Furthermore, a number of extensive savannah or grassland habitats, known as 'sandveld tongues', extend into the Delta from the surrounding Kalahari. These savannah habitats range from flooded grasslands to non-flooded savannahs and different types of seasonally flooded savannahs. Around the edges of the Delta and on Islands, dry woodlands as well as riverine woodlands are found (Alonso and Nordin 2003; Junk *et al*. 2006a; Mendelsohn and El Obeid 2004; Pendleton and Baldwin 2007; Ramberg *et al*. 2006; Ross 2003).

The complex pattern is mainly caused by ever changing river courses and the growth of islands of land higher than the annual flood level, which are scattered throughout the Delta. There may be as many as 150,000 islands, 70 % of which probably developed on original termite mounds (Fig. 2.15A) (Mendelsohn and El Obeid 2004). The termites responsible for building the islands in the Delta are fungus termites. Their activities cause patches of land to rise above the flatness of the terrain and the soil to be enriched, encouraging the growth of trees. Termite mounds may be built in the dry season, when there is little or no water in an area and as they grow, their bases join. The land surface, thus, rises and prevents water from flowing over the formerly flooded area. In time, trees colonise the dried floodplains and the termites keep building. If several mounds are built close together they may join to from large islands. The island-building activities of the termites are continuous and the Delta's waterways are constantly changing. This constant change also helps to keep the Delta’s water fresh (Ross 2003).

Furthermore, the Okavango Basin’s area is not only limited to the active catchment area from which water drains, plus the zone immidiately surrounding the currently flowing rivers and the Delta. It actually covers a much larger area when one includes the ephemeral rivers and fossil drainage lines, which used to flow during wetter periods long ago (Fig. 2.6) (Mendelsohn and El Obeid 2004). After heavy rains, some water still flows along the ephemeral rivers, but the fossil rivers have not had water in living memory and haven’t flowed into the Okavango for decades. Many of these fossil rivers drained from Namibia, into the Delta, for example the Nhoma River which entered the fan-shaped Delta south of Gumare and the Nxamasere River which used to flow into the Panhandle at Nxamasere.

Presently, during times of flooding in the Delta, water pushes up into these fossil rivers, creating unique foodplains, which are extremely productive (Fig. 2.14A - D). Animals thrive in floodplains such as those at Nxamasere. It creates pools in which hippos wade, plankton flourish and, consequently, fish thrive. Frog and toad numbers in the Nxamasere Floodplains are so high, that their croacing is defening. When water levels start to drop and the Nxamasere pools begin to dry, the fish become concentrated and birds have a feast. Riparian forests grow along the edges of this fossil river, while the centre is covered by green grass and the pools have patches of papyrus and water lilies scattered across them.

The riverine Panhandle and upper permanent swamp habitats cover two-thirds of the area of the Delta (Alonso and Nordin 2003). When classifying habitats based on a combination of life form characters and dominant species, a total of 46 habitats can be identified. Areas with the least stable and most unpredictable environments have the highest habitat diversity (Mendelsohn and El Obeid, 2004). From the variety of habitats follows the wealth of plants, animals and scenic beauty that gives the Delta such great value.

CLASSIFICATION OF WETLAND SPECIES

Large wetlands represent a complex of permanent, aquatic, palustrine and terrestrial habitats, and in the case of river floodplains, there are aquatic/terrestrial transition zones that dry out periodically. Therefore, a broad approach must be used to biodiversity, when making comparisons (Junk *et al*. 2006a). Too often, permanent aquatic species (obligate species) are the only species taken into account when conservation plans etc. are made. Gopal and Junk (2000) defined wetland species as "all those plants, animals and micro-organisms that live in a wetland permanently or periodically, (including migrants from adjacent or distant habitats) or depend directly or indirectly on the wetland habitat or on another organism living in the wetland". A broad description is essential for wetland management and conservation, as many species depend on wetlands to varying degrees and can be classified accordingly (Table 2.5). Many organisms share habitats such as rivers, lakes, wetlands and adjacent uplands during different parts of their life cycles and, therefore, a firm separation between organisms living in is these separate habitats is impossible (Junk *et al*. 2006a).

Table 2.5: A classification of wetland species according to their behaviour, occurrence and dependence on wetlands (compiled from Junk *et al*. 2006a).

1. Residents of the wetland proper
   1.1. Obligate residents of wetlands
      1.1.1. Endemic species
      1.1.2. Non-endemic species
   1.2. Non-obligate residents of a wetland

2. Migrants
   2.1. Regular migrants from deep-water habitats
      2.1.1. Regular freshwater migrants
      2.1.2. Regular marine migrants
   2.2. Regular migrants from terrestrial uplands
   2.3. Regular migrants from other wetlands
   2.4. Occasional visitors

3. Parasites, pathogens and other dependents

SPECIES DIVERSITY

According to Mendelsohn and El Obeid (2004), most of the Okavango's rivers have low fish stocks and numbers of wildlife. In the Delta, however, biological production is rich because of the considerable accumulation of nutrients at the end of the river system. There are many disagreements as to whether the Okavango Delta has high or low total species diversity.

Ramberg *et al*. (2006), for example, state that when comparing the Delta's biodiversity with that of other countries in the southern African region, results indicate that it is slightly higher than for Botswana (the country in which it is situated), probably reflecting the larger contribution of aquatic species. They carry on to say that, with the exception of the Cape Floral kingdom, which is a unique area, the species richness in the Okavango Delta is in the range of the other biomes in the southern part of the southern African sub-continent and can be considered to be “normal”. However, when looking at species diversity in a global context, it may be a different situation. In comparison to other globally important wetlands, the Okavango may have “high” or “low” species richness.

Thomas and Shaw (1991), on the other hand, argue that the Okavango Delta has been identified as one the most botanically rich areas in southern Africa and that about 1,061 species were recorded at a species/area ratio of 0:0545. This level of diversity, once again, is only surpassed by the Fynbos region of southern South Africa.

Most large mammals of the Okavango Delta are well-documented and well-known, but the aquatic organisms of the Delta have received attention to a lesser degree. Ramberg *et al*. (2006) wrote an article in which they attempt to summarize available data on the species diversity of the Okavango Delta. According to them there had been no systematic attempts to analyze Okavango Delta biodiversity and the factors that are causing and regulating it, prior to theirs.

Floral communities in the Delta cover a wide range from savannah woodlands and riverine forests to aquatic grasses and perennial swamps, not to mention the sand islands and permanent water (Thomas and Shaw 1991).

Algae

The status of knowledge on algae has to be considered insufficient to make statements about the diversity. There exists no record of algae composition in the Okavango Delta. Cronberg *et al*. (1996) sampled rivers, floodplains and isolated pools in the Okavango Delta during four occasions in 1991 and 1992 and found a total of about 50 species. The sum of algal species cannot be estimated, but is probably several hundred (Ramberg *et al*. 2006).

The Okavango Delta belongs to the Zambesian Phytochoria, which is one of 16 areas in Africa defined as having more than 50 % endemic plant species and a total of more than 1,000 such species. Several botanical studies were conducted between 2000 and 2002, leading to a list of 1,299 species and subspecies. It has been concluded that the total number of species and lower rank taxa in the Okavango Delta is more or less 1,405. However, the inaccessible eastern parts, especially, have barely been studied while most of the studies have been done in the central two-thirds of the Delta. Therefore, the total number of species is possibly much higher than that proposed (Ramberg *et al*. 2006).

Herbaceous Plants

Large numbers of herbaceous plants are reported from the Okavango Delta and can be due to the large habitat diversity of the wetland. About 1,150 species were recorded from the Delta, of which 70 % are terrestrial species. Flood amplitude, water transparency, shading by trees and salinity, amongst others, have an effect on the species diversity of aquatic macrophytes. In the Okavango Delta, shallow flooding with transparent water, little shading by trees and low salinity allow the growth of an extremely diverse and luxuriant aquatic and palustrine vegetation consisting of about 350 species (Junk *et al*. 2006a).

In the Okavango Delta there are two main species of water lily which are *Nymphaea nouchali* var. *caerulea* (Fig. 2.15B) and *Nymphaea lotus* (Fig. 2.15C). The latter is the yellow night lily which occurs in the deeper waters of channels and around the fringes of larger lagoons while the *Nymphaea nouchali* var. *caerulea* is day-flowering and grows in shallow, still waters throughout the Delta. The *Nymphaea nouchali* var. *caerulea*'s flowers occur in a range of colours, from dark blue to pink or white and are more finely structured than those of *Nymphaea lotus*, which has serrated lily pads.

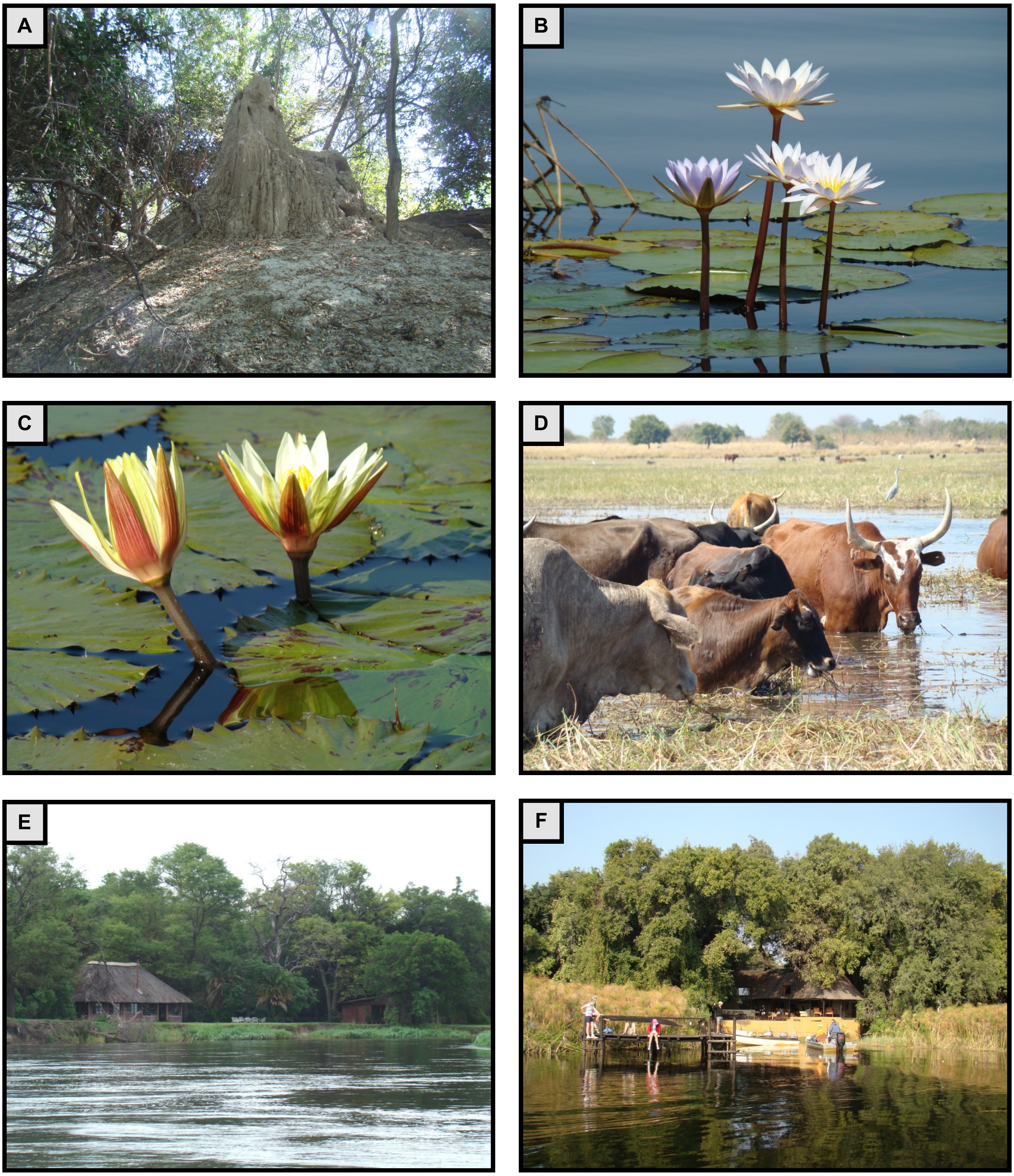


Figure 2.15: (A) Termite mound on an island. **(B)** The day-flowering water lily, *Nymphaea nouchali* var. *caerulea.* **(C)** The night lily, *Nymphaea lotus.* **(D)** Local people's herds of cattle grazing in the floodplains of the Panhandle. **(E)** Samochima Fishing Camp at Samochima Village. **(F)** Nxamasere Lodge, situated on the banks of the Nxamasere Channel.

Woody Plants

In terrestrial ecosystems, the number of species of woody plants increases as one moves towards the equator. The more arid southern parts have a lower woody plant species diversity. Only about 180 species of woody plants are recorded from the Okavango Delta. This may be due to the low rainfall in the region (Junk *et al*. 2006a).

Invertebrates

Invertebrate densities, species numbers and community structures fluctuate greatly when water levels fluctuate, as a result of the flooding patterns. This has been observed in the Okavango Delta for which the data on invertebrate species is far from complete. Some taxanomic groups are too difficult to collect, or have never been sampled by anyone, while others are taxonomically not well known or there are no taxonomists capable of identifying them (Ramberg *et al*. 2006).

Sufficient information exists for Odonata, with a total of 94 species found in the Delta out of 114 species in Botswana. There are strong similarities in Odonata composition with wetlands to the north, which, at wetter times, were directly connected to the Okavango.

Studies on butterfly species in the Delta have only been done on the western side due to the inaccessibility of the eastern portion of the Delta in the past. One hundred and twenty four species were collected on the western side. The Okavango Delta is a focus of butterfly diversity in Botswana as it is a wetland area with a wide range of larval flood plants and angiosperms which provide nectar for the adult butterflies while the rest of Botswana is a semi-desert area (Ramberg *et al*. 2006).

The occurrence of aquatic snails (mollusca) have been well documented - a total of 22 species. Furthermore, about 37 species of microcrustaceans have been described, consisting of 16 species of copepods and 21 cladoceran species (Junk *et al*. 2006a). Large groups of invertebrates such as Acari, Rotifera, Nematoda and many others have not even been mentioned.

Fish

The number of fish species found in a wetland is related more to the number of species found in the parent river rather than to the size of the wetland. This is because parent rivers are hydrologically more stable than wetlands and during severe hydrological and climatic events, both in the past and the present, they serve as refuges for species. For example, 83 % of the fish fauna that occur in the Okavango River occur in the Delta (Junk *et al*. 2006a).

As mentioned earlier, the Okavango system used to be connected to the Zambezi drainage basin and its fish fauna can be considered as being part of the Zambezi system. However, the Okavango system has a lower fish fauna than that of the Zambezi River system. The Zambezi system has 134 fish species of which 86 are found in the Okavango system and only 71 of the 86 species are found in the River and Delta below the Popa Rapids of the Caprivi Strip in Namibia (Ramberg *et al*. 2006). The other 15 species are restricted to the rocky areas in the Angolan highlands.

Amphibians

All amphibians are dependent on water, either for their reproduction, or for the deposition and hatching of their eggs, in some cases for both. In total, 33 amphibian species have been recorded in the Okavango Delta. The same species (no more, no less and no different) have been recorded for the whole of Botswana. Twelve (32 %) of these species are restricted to the Okavango and the Chobe and eight (24 %) to the Delta only. They do not occur in the rest of Botswana. These species are tropical and in the Delta they find themselves in the southern end of their distribution. The majority of the 33 species found in the

Delta occur close to water and only three to five species are more terrestrial (Ramberg *et al*. 2006).

Reptiles

Out of 64 reptile species documented from the Delta, four terrapins, the Nile crocodile and one snake species are confined to water. Four snake species of the Colubridae as well as the python mainly occur in swamp habitats. Among the 64 species of reptiles, there are 10 species whose distribution in Botswana is restricted to the Okavango and the Chobe and 52 are terrestrial (Ramberg *et al*. 2006).

Birds

Birds aggregate around water bodies and all wetlands are rich in bird species. There are many observations on their occurrence and behaviour and the data is adequately elaborated (Junk *et al*. 2006a). Due largely to the efforts of amateur birdwatchers, the number and variety of birds in the Okavango Delta is well documented. These bird watchers contributed substantial data to the Bird Atlas of Botswana and there are 444 confirmed bird species in the Delta, making it, together with the Chobe River, the most species rich area in Botswana. The avifauna of the Okavango can not easily be classified into wetland-restricted species and those that are not restricted to wetlands (Ramberg *et al*. 2006). For the purpose of comparison, Ramberg *et al*. (2006) have defined three categories namely aquatic species (those that feed by diving, swimming, wading etc.), non-aquatic species (those that inhabit wetland habitats) and terrestrial species not restricted to wetlands. The numbers of species in each category are 112, 57 and 275, respectively. Three hundred and thirty nine species (76 %) of birds found in the Okavango Delta are breeding residents and a noteworthy number of Palaearctic migrants (29.3 %) visit the Okavango specifically because of its wetland habitats.

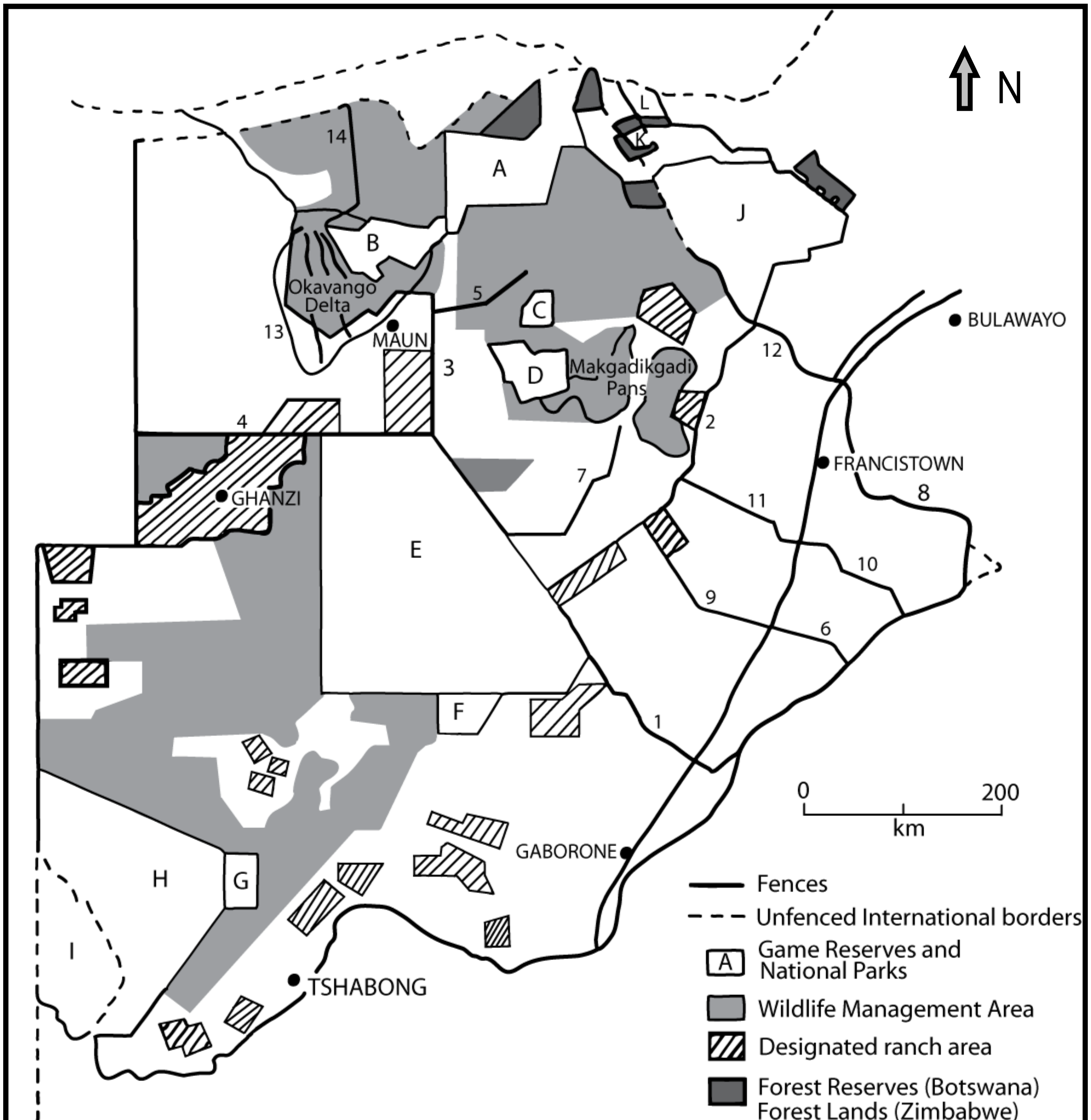
Mammals

The Okavango Delta has a wide variety of large mammals (122 species) occurring locally in high numbers, but most mammals in the Delta are fairly small and are often overlooked. Factors such as habitat diversity, connectivity to species pools in the Southern African region and the environmental history of the Delta determine the overall mammal biodiversity of this whole community. All the larger species are widely spread across the African Savannah region and typical forest species do not occur in the Delta, even though the riverine woodlands often have closed canopies. The patchiness of these woodlands might be preventive of such species. Similarly, no mammals typical of rocky outcrops are present, as there are no such habitats in the Delta. If one compares the Okavango wildlife biomass with regression models between rainfall and rainfall and nutrient level, it is four to eight times higher than expected. One of the reasons for this is the prolonged productive period caused by annual flooding (Ramberg *et al*. 2006).

The biomass of the large mammals in the Okavango Delta is about 12 t/km^2. Prior to fencing parts of the Delta, its biomass was even greater, as large herds of ungulates migrated to the Delta from the surrounding savannahs and deserts during the dry season (Junk *et al*. 2006a). When the “buffalo” fence was constructed in 1982 (Fig. 2.16), it denied numbers of wild animals access to the Delta, but it has also successfully controlled the numbers of domestic animals (such as cattle) entering the Delta.

Endemic Species

Despite the large number of species in the Okavango, the number of endemic species is extremely low. The Slaty Egret is the Okavango’s only near-endemic species, with 85 % of the global population occurring there. It has the Okavango Delta as its centre of distribution. The low number of endemic species can, in part, be explained by the fact that this wetland was, in its recent history,



National Parks and Game Reserves:

A - Chobe National Park, Botswana
B - Moremi Wildlife Reserve, Botswana
C - Nxai Pan National Park, Botswana
D - Makgadikgadi Pans Game Reserve, Botswana
E - Central Kalahari Game Reserve, Botswana
F - Kutse Game Reserve, Botswana
G - Mabuasehube Game Reserve, Botswana
H - Gemsbok National Park, Botswana
I - Kalahari Gemsbok National Park, South Africa
(H + I) - Kgalagadi Transfrontier Park
J - Hwange National Park, Zimbabwe
K - Kazuma Pan National Park, Zimbabwe
L - Zambezi National Park, Zimbabwe

Veterinary Cordon Fences:

1 (1954) Dibete Cordon Fence
2 (1955) Central Ngwato
3 (1955) Ngamiland
4 (1958) Kuke
5 (1968) Shorobe - Chobe
6 (1977) Palapye - Sherwood
7 (1979) Orapa
8 (1979) Vakaranga - Tuli
9 (1981) Makoro - Makoba
10 (1981) Serule - Limpopo
11 (1982) Serule - Thalamabele
12 (1982) Vakaranga - Tomasarka
13 (1982) Gomare - Shorobe ('Buffalo Fence')
14 (1989) Northern Fence

Figure 2.16: Botswana's national parks, game reserves, veterinary cordon fences, wildlife management areas and designated ranch areas (redrawn from Thomas & Shaw 1991).

connected to large river basins which served as migratory routes or for passive transport of aquatic and even terrestrial organisms, between the entire catchment area and the Delta. Furthermore, water level fluctuations and habitat dynamics support the mobility of the species inside the Delta and delay speciation by permanent gene flow between subpopulations (Junk *et al*. 2006a). The Okavango Delta is also of relatively young age and not enough time has been allowed for speciation to take place.

Endangered Species

Four species of butterfly in the Okavango Delta are rare, though not endangered or vulnerable. Six globally threatened and near-threatened bird species occur in the Delta. In this wetland, invertebrate numbers declined dramatically after spraying to control or eliminate the tsetse fly. It is likely that some of the less common taxa were eliminated totally while some of the aquatic families affected by spraying remained at reduced numbers, particularly shrimps and small backswimmers (Ramberg *et al*. 2006).

PEOPLE OF THE OKAVANGO

The Okavango Basin has never been an easy place to live, or at least in comparison to many other areas in southern Africa. Historically, most people chose to live in other places that offered better agricultural potential and economic opportunities, and where they and their livestock were safer from diseases. The Basin's population has never really been big, and even now it makes up a tiny proportion of all the citizens of Angola, Namibia and Botswana (Mendelsohn and El Obeid 2004).

Population Density

Those within the Basin area in Angola make up less than 3 % of the total Angolan population, while equivalent proportions for Namibia and Botswana are 7 % and 5 %, respectively. In 2004, the total population in the entire Basin (the catchment area in Angola and within 20 kilometres of the river in Namibia and Delta in Botswana) was estimated to be 600,000 people. Estimates suggest that approximately 58 % (350,000) of all people live in the Angolan catchment. However, no censuses have been conducted in recent decades in Angola and so the estimates have been based on a variety of sources. Approximately 27 % (163,000) of the Basin's population live in Kavango in Namibia and only 15 % (88,000) in Ngamiland in Botswana. The totals for Ngamiland and Kavango are most accurate because they are based on national censuses which were held during 2001 (Mendelsohn and El Obeid 2004).

In Botswana, about 50 % of the Basin population is considered to be urban, compared to 26 % in the slightly wetter Caprivi Strip and only 14 % in the water-rich catchment in Angola. Of the 88,000 people living in the basin in Botswana, 44,000 live in Maun, the only officially recognized town in Ngamiland, and lead lives that are independent of rural livelihoods. The only recognized town in Kavango is Rundu, while in Angola, Menongue and Cuito Cuanavale can both be called urban areas. In addition to these four large towns, there are many large rural villages in which residents usually farm nearby, each being home to more than 1,000 people. In Angola the most prominent are Longa, Luassinga, Chitembo, Mumbué, Cuchi, Cutato and Kubango, while in Namibia they are Nkurenkuru, Kahenge, Ndonga, and Divundu. In Botswana, from upstream to downstream the most prominent large rural villages are Mohembo (at the Namibian border), Shakawe, Nxamasere, Sepopa, Seronga (the only large village on the eastern side of the Panhandle), Etsha, Gumare and Nokaneng (Fig. 2.7) (Mendelsohn and El Obeid 2004).

The number of people in Kavango and Ngamiland has grown rapidly over the past 90 years or so. This is mainly as a result of lower child mortality and longer life spans, due to the introduction of modern medical services. In the early 20th century, Ngamiland had about double the population of Kavango. This continued until the early 1970s. However, Kavango experienced very rapid growth from the 1970s onwards and soon its population overtook that of Ngamiland's. The rapid growth in Kavango has mainly been due to the arrival of Angolan immigrants during hostilities associated with Angola's independence war. The effects of the recent immigrations can be well illustrated by the following. Before the 1970s, Ngamiland and Kavango had average growth rates of 2 % and 3 %, respectively. If Kavango's population had continued to increase at an annual growth rate of 3 %, the total population would have increased from 26,900 people in 1961 to about 88,000 in 2001. However, the number of people in 2001 was a staggering 201,000 due to immigration (Mendelsohn and El Obeid 2004).

Both Maun in Botswana and Rundu in Namibia have grown from tiny villages 40 years ago, to towns with over 40,000 residents. Approximately one in four people in the Basin area of Kavango and one in three people in Ngamiland now live in Rundu and Maun. The annual growth for the two towns has been over 6 % during the past 20 years, and the towns will probably double in size over the next 12 years if that rate continues. The main reasons for people moving to town are to find a job or to go to school. Therefore, the populations of Maun and Rundu are dominated by school-goers and adults between 20 and 40 years of age. Much of the changes in Angola were due to the displacement of people and towns that grew rapidly, did so, because troops forced the closure of many rural villages, which were thought to provide support and food to UNITA. The villagers were then moved to towns. Many people also sought refuge in towns away from soldiers and the continual conflict in the Basin (Mendelsohn and El Obeid 2004).

Languages or Dialects

There are fourteen major groups in the Basin that (some more, others to a lesser degree) speak distinct languages or dialects, of which eleven are of Bantu origin and three are Khoesan Languages. The Ovimbundu people mainly live in the most north-western part of the catchment, but the Angolan section is dominated by Ganguela and Tchokwe people. There is, however, a high degree of mixing and many Ovimbundu, Ganguela and Tchokwe speakers now live in Kavango. About one-third of Rundu's residents have an Angolan language as their mother tongue. There are five distinct tribal areas along the border between Angola and Kavango (Namibia). The two most western of these tribes, the Kwangali and the Mbunza, share the Rukwangali language, but they have separate tribal authorities. The same goes for the Shambyu and Gciriku people who speak slightly different dialects of the Rumanyo language. The Mbukushu people are further east and extend down along the western margin of the Delta. They make up the majority of the residents in the Delta and include the Bayei, Tawana and Herero people (Mendelsohn and El Obeid 2004).

The San

The small numbers of San in the area can be divided into Khwe and Ju language groups. Khwe people mostly live to the east of the river in Kavango and the Delta in Ngamiland where certain subgroups are often called the River Bushmen. The Ju language group is comprised of a sub-group who live on the western edges of the Delta and the small numbers of people of !Xun in Angola. Many Khwe and !Xun people have been displaced in recent years in Angola and Kavango due to hostilities and political difficulties (Mendelsohn and El Obeid 2004). The story of the San is quite interesting and, today, is almost tragic.

The San or Bushmen, as they are often called, are the oldest of Africa's people and the earliest race to settle for the harshness of the Kalahari. Never in the history of Africa have people lived for such a long time in an area without changing or destroying it. Being hunter-gatherers, they did not need to grow crops or keep livestock, nature provided. The tragedy is that very few Bushmen remain today and live as their ancestors did. There was a time that Bushmen thrived, occupying most of Africa. Sadly, they gradually lost ground to more ambitious and aggressive races and the Kalahari became one of their final hunting grounds (Ross 2003). Today, very few !Xun San remain in Angola because of often being displaced by hostilities. Many fled from Angolan forces in 1999 and several thousand Angolan San were also resettled, by the South African Defence Force, in the former area called ‘Bushmanland’ in Namibia in the early 1970s. Just before Namibia’s independence in 1989, a large number of San were taken to Schmidtsdrift in South Africa (Mendelsohn and El Obeid 2004). More recently, their much publicised eviction from their traditional lands, in the Central Kalahari Game Reserve (Fig. 2.16), was seen by many as an injustice, which clouded Botswana’s, otherwise well-respected, democracy (Ross 2003). Therefore, during 2008, the Botswana government allowed them back, but only under certain conditions and with strict, unfavourable rules.

The way of the San is an excellent example of humans living harmoniously, not destructively, with mother nature. Their way of life, unselfish manners, knowledge of the fauna and flora surrounding them and their understanding of the intricate connection between all species sharing their environment is truly something to admire. The Bushmen probably never lived in isolation from outside influences and those San who no longer lead a hunter-gatherer lifestyle, together with the other people of the Okavango Basin, use the land and its resources in a variety of other ways, but much more land is used for farming than for any other purposes.

Farming

Farming, however, is not so simple in Ngamiland. Factors such as soil quality, rainfall, evaporation, diseases and pests all limit farming activities and then there are socio-economic factors such as household labour, availability of land and access to other income that affect farming too. Furthermore, grasses vary in abundance and nutritional quality while fires destroy hundreds of kilometres of pastures on which livestock depend (Mendelsohn and El Obeid 2004).

The majority of people rely heavily on farming for most or even all their food needs, but there are the fortunate few who have alternative sources of sustenance and income. There are about 8,500 farming households close to the Delta in Ngamiland and each household normally cultivates a few hectares of mainly millet, maize and sorghum and sometimes keeps small herds of cattle (Fig. 2.15D) and goats. About 95 % or more of all farming is practised on more or less this basis and most of the farmers live in rural areas, concentrated in villages, while south and away from the Delta, in Ngamiland, several hundred commercial farmers have large herds of cattle (Mendelsohn and El Obeid 2004).

Fishing

Fishing has also been serious business for a long time in the Okavango. Mendelsohn and El Obeid (2004) state that the Swedish explorer and so-called discoverer of the Okavango River, Charles John Andersson, wrote the following in his book; *The Okavango River. A narrative of travel, exploration and adventure* (Andersson 1861) - 'many of the natives devote a considerable portion of their time to fishing, and employ various simple, ingenious and highly effective contrivances for capturing the finny tribe'. This still holds today. Many locals still spend hours fishing for what will be their household's next serving of food and their main protein meal (Fig. 2.14C).

Kgotla System

In Botswana, there is a kgotla system in every village. This is the chief's court where elders sit in a semi-circle, usually in chairs, while most of the crowd settles on the sand. This system is a part of Botswana's democratic tradition and everyone is allowed to speak for as long as they wish, while the chiefs and dignitaries are obliged to listen. Women attend the kgotla too, although they sit separately from the men. The kgotla is the true forum for debate in Botswana and it is said that it is the most powerful tool of each tribe. The chairs under the trees, in the sand, that mark the chief's court have real power (Ross 2003).

THE IMPORTANCE OF A RIVER AND DELTA

In southern Africa, water is scarce and its presence determines how well people survive and its absence leaves large areas uninhabitable (Ross 2003). The Okavango River is, therefore, a critical resource and a permanent source of water for the people and wildlife of the arid Kalahari. Upstream water resources are abundant, but mid and downstream sections of the basin are dry and therefore, the Okavango's water is an extremely valuable good, whether for human needs or to sustain ecosystems (Kgathi *et al*. 2006). The Okavango River Basin delivers an average of 9.4 km^3 of water per annum into the Kgalagadi sands at the top North-western corner of Botswana, turning an otherwise desert area into a wetland of international importance (Magole 2008). It contains unique terrestrial and aquatic species, intricate connections between water and land, and dramatic seasonal flooding cycles, supporting over 15,000 people.

A substantial proportion of the population in the three basin countries still live below the poverty datum line and due to this high incidence of poverty, the majority of the people depend on natural resources freely available from the river and surrounding areas to support their livelihoods (Kgathi *et al*. 2006). The aquatic ecosystems provide freshwater, food, transportation and habitat for the local and regional communities, as well as for wildlife.

In Botswana, resources of the Okavango Delta support a diversity of livelihoods, ranging from agriculture production to tourism enterprises (Figs. 2.15E & F) (Magole 2008). The seasonal swamps are extensively used for flood recession farming in the peripheral parts of the Delta (Murray-Hudson *et al*. 2006).

In addition to acting as a water regulator in an arid land, the Delta attracts large-scale migrations of mega-fauna and is home to a few endangered species, making this a wilderness of global biological significance. The floodplain grasslands support densities of herbivores that are seasonally considerably higher than those in the surrounding woodland and savannah. Many fish species migrate long distances along the river system between Angola, Namibia and Botswana. Dry land, close to the Delta's water, supports a diverse and productive riparian woodland, which is entirely dependent on groundwater supplied from the adjacent floodplains or channels (Alonso and Nordin 2003; Murray-Hudson *et al*. 2006).

The Okavango River is best known for its Delta, which is maintained by the annual pulse flooding of the Okavango River (from the highlands of central Angola), creating one of Africa's largest wetlands and the world's largest inland wetland systems (Alonso and Nordin 2003; Kniveton and Todd 2006). Remarkably, the Okavango River is one of only 20 % of the world's rivers that are still wild. In other words, it does not have any major works, such as dams, along its course (Ross 2003). The Botswana government also recognized what an exceptionally important resource the Okavango Delta is, particularly in terms of its conservation and tourism value, and through the provision of a wide variety of ecosystem resources and services to local residents (Alonso and Nordin 2003). When in 1996, the Botswana government designated the Delta an International Ramsar Site (Fig. 1.1), it placed the area in the global arena. The Okavango Delta has unique habitats with extraordinarily high beta diversity and, as such, is one of the World Wildlife Federation's (WWFs) top 200 eco-regions of global importance (Kniveton and Todd 2006) and is currently one of the world's largest Ramsar sites.

The Okavango Delta is considered to be a wetland of global importance and was included in a special issue of *Aquatic Sciences* in 2006 (Ramberg *et al*. 2006), in which the biodiversity of seven such globally important wetlands were compared. These wetlands included the Canadian peatlands (Warner and Asada 2006), the Florida Everglades in the United States of America (USA) (Brown *et al*. 2006), the Pantanal in Brazil (Junk *et al.* 2006b), the Sundarban Mangrove Ecosystem

(Gopal and Chauhan 2006), Cambodia's Tonle Sap Great Lake (Campbell *et al.* 2006) and wetlands in the Kakadu region of northern Australia (Finlayson *et al*. 2006).

The Delta has a biodiversity similar to that of other wetlands in the southern African region, but is its species diversity high or low when compared to other globally important wetlands? The most appropriate wetland to compare it with is the Pantanal in South America, as they share a number of similarities. Both are situated in the southern hemisphere at more or less the same latitude and are fed by major river systems. The Okavango Delta by the Okavango River and the Pantanal by the Paraguay River and many smaller rivers.

These wetlands have a tropical climate of wet and dry cycles, with extreme flood and drought events. The Okavango Delta and the Pantanal are typical flood-pulsed systems, with monomodal pulses and two flood periods every year. Inflowing water from the catchment areas reach these wetlands via the Okavango and Paraguay Rivers, respectively. Low elevation in the two areas causes water to travel slowly and flood waters reach the northern parts about 3 months before it reaches the most southern points, while the second flood period is caused by local rainfall in the areas of the wetlands themselves.

Being inland wetlands, they don't include marine species and have large habitat diversities, due to various factors, but mainly due to the flood regimes and local differences in elevation. The Okavango Delta and the Pantanal have similar habitats and vegetation types, such as shallow lakes, rivers, channels and different types of flooded savannahs.

Both wetlands are of a mesotrophic status and sustain large populations of higher animals. Despite the present human activities they both remain pristine and underdeveloped compared to other major wetlands. Furthermore, frequent fires occur in these areas with serious effects on biodiversity.

Results show that little studies have been done on species diversity in wetlands. This makes comparative studies difficult or even impossible. Except for obligate species in these two wetlands, they seem to reflect the species composition of their surrounding eco-regions. The Pantanal houses a greater diversity of higher plants, fish, amphibians and reptiles, while the Okavango Delta boasts with more bird and mammal species. Too little data is available on algae and invertebrates to be able to make a meaningful comparison. The Pantanal has a slightly larger diversity than the Okavango Delta, which may be attributed to a number of factors, such as differences in rainfall and bordering eco-regions.

At the 2005 World Summit in New York, the secretariats of five international biodiversity-related conventions called upon the world's leaders to recognize that biodiversity has to be used sustainably and that sharing of benefits should be more equitable. In a highly populated planet, this is crucial in making the Millennium Development Goals a reality. The five global conventions included:

- Convention on Biological Diversity (CBD);
- Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES);
- Convention on Migratory Species of Wild Animals (CMS);
- Ramsar Convention on Wetlands; and
- World Heritage Convention.

Furthermore, wetlands should be placed on the top of the priority list of ecosystems, due to their high species richness, high vulnerability and the great amount of pressure being placed on them, because of their commercial and non-commercial value (Junk 2006).

Unbelievably, the special issue of *Aquatic Sciences* was, at the time (2006), the first attempt (Junk 2006) to gather data on the species diversity of large wetlands around the world, with different hydrological regimes. Hopefully it was a good starting point.

Chapter 3

MATERIALS AND METHODS

LESEDING RESEARCH CAMP

The Leseding Research Camp (Fig. 3.1A - D) of the Aquatic Parasitology Research Group (University of the Free State) is situated on the premises of the Krokavango Crocodile Farm, next to Samochima Lagoon, and on the fringes of Samochima Village. The lagoon and village lie on the western side of the Upper Panhandle, close to Shakawe. Leseding Camp does not only boast with tented accommodation (Fig. 3.1B), ablutions, a kitchen (Fig. 3.1D) and “braai” facilities, but also has a sufficiently equipped laboratory (Fig. 3.1C), as well as an aquarium, making it the perfect base from which studies were conducted.

STUDY SITES

Two motorboats, *Clarias* and *Synodontis* (Figs. 3.1E & F), were used to access the river, channels and lagoons, all the way from Mohembo at the Namibian border to Guma Lagoon in the north-western tip of the Delta Fan. Various sites were sampled from Popa Falls in Namibia to Guma Lagoon (Figs. 3.2 & 3.3) and were named OR2 to OR125 and OR128 to OR144, except for a few locations that were given other names. These include: Guma, Kamaisl, Xaro, Swampstop, SL2, Nxamalodge, Drotsky and DW60/SL1. Samples taken at the Nxamasere Floodplains were named NX3, NX4 and NX6 and those taken at Popa Falls PF (PF1 to PF7). The 159 study sites covered the widest possible range of different habitat types present in the Okavango Panhandle. Samples were taken in the main river, side channels, lagoons, deep waters, shallower floodplains, isolated pools and between reeds and papyrus. Furthermore, samples were also taken at Lake Ngami and in the Nchabe/Kunyere River at the village of Toteng.

Prior to any field measurements of sample collection, the precise position of each sampling site was noted with a Garmin- etrek Geographical Positioning System (GPS) for the first two trips and a Garmin- Colorado for the last two. The site location data will allow for the sites to be re-visited, if so required.

A list of the study sites and the GPS coordinates of each of these sites can be found in Appendix 1.

FIELDWORK

Four field trips were conducted between December 2006 and January 2009, which covered different levels of flooding from low to high water levels. From Leseding Camp, a fair amount of travelling is needed to reach the various

Figure 3.1: (A) Leseding Research Camp. **(B)** Sleeping quarters at Leseding. **(C)** At work in Leseding Laboratory. **(D)** Supper preparation in the kitchen at Leseding. **(E)** Loading luggage and equipment on *Clarias* and *Synodontis* for the trip down to Seronga. **(F)** *Synodontis* on the Okavango River. **(A), (C), (D), (E) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

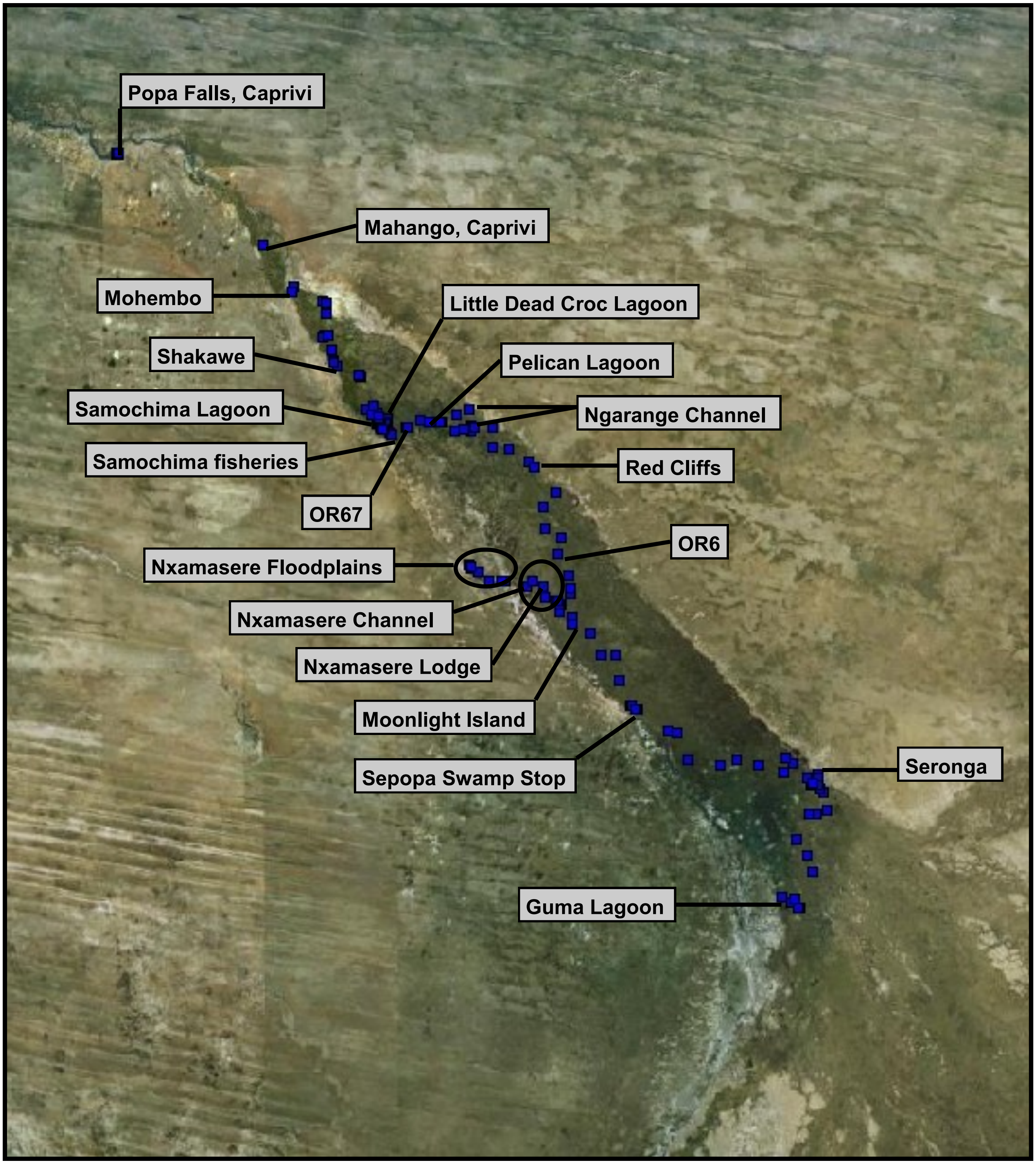


Figure 3.2: Various sites sampled along the Okavango River and Delta, as well as an illustration of sampling points or areas of interest, concerning the water quality of the unprotected Okavango Delta.

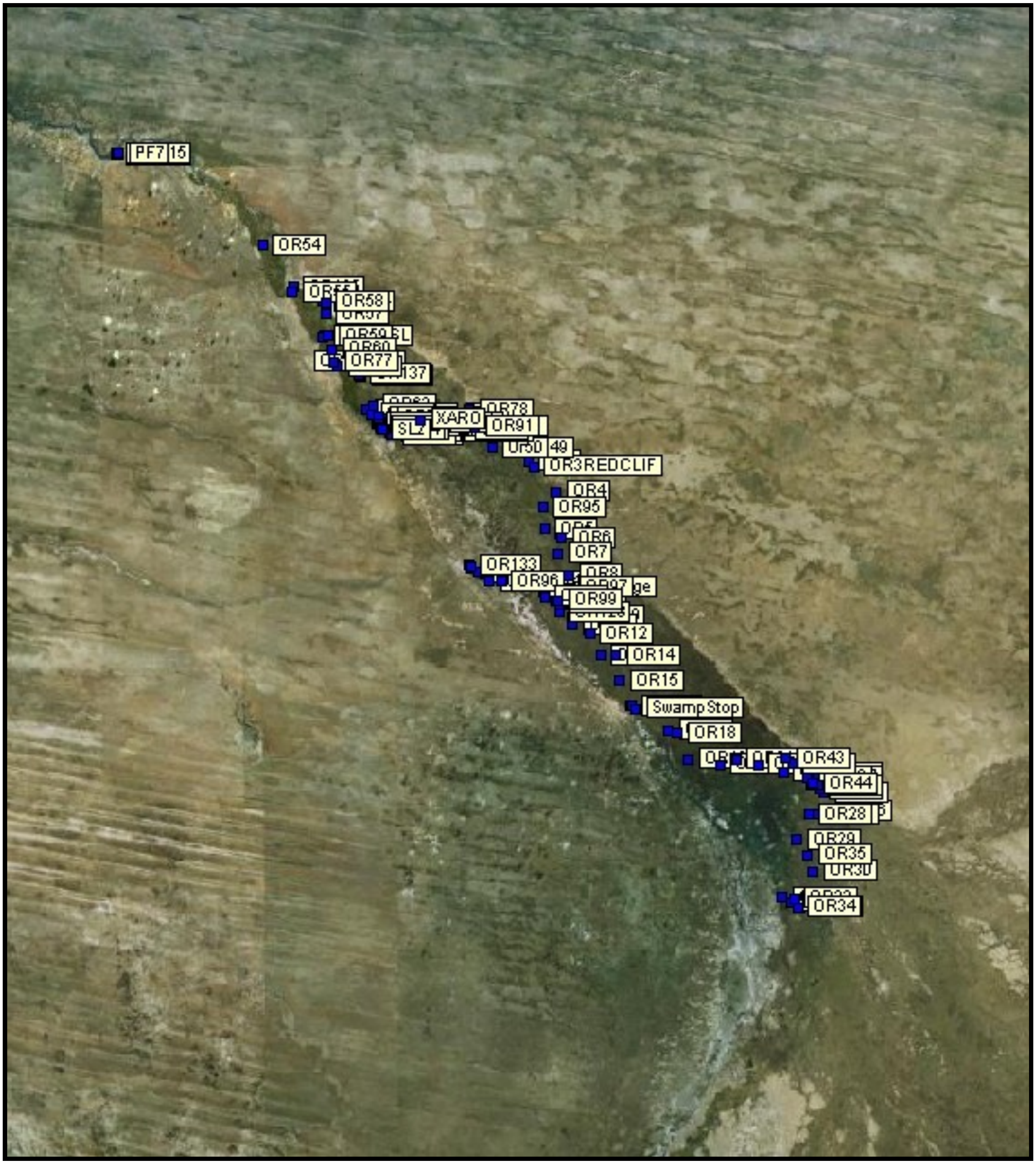


Figure 3.3: Various sites sampled along the Okavango River and Delta. Samples were taken from Popa Falls in the Caprivi Strip all the way to Guma Lagoon at the south-eastern tip of the Delta Fan.

sampling sites in and around the Delta. Sites were visited either by vehicle, or by boat. Places such as the Nxamasere Floodplains (Figs. 3.5E, 3.6F & 3.7C), Popa Falls (Figs. 3.6E & 3.7A) and Lake Ngami (Fig. 3.5B & 3.7D) were accessed by vehicle. Where the Okavango River itself touches the mainland, samples could also be taken from the land. On the other hand, the rest of the areas within the Panhandle could only be accessed by boat (Fig. 3.6C). Data-collection trips such as these, be it on land or on the water, require different time spans, depending on how far the area, which has to be sampled, is from the base camp. Return trips to Popa Falls (by vehicle), Mohembo (by boat or vehicle), Nxamasere Floodplains (by vehicle), Sepopa (by vehicle) and Red Cliffs (by boat) for example, require only one day. When travelling to Nxamasere Channel or Moonlight Island, which can only be reached by boat, or to Lake Ngami (by vehicle), more than one day, at least two, is needed for a return trip. Travelling to Seronga (by boat) requires at least four days. Therefore, there are various degrees of logistical arrangements which have to be made beforehand.

The basic things needed for every trip are:

- Water meters;
- Secchi disk;
- Sampling bottles;
- Coolers (to keep samples cool and protect water quality meters from the heat);
- Waders;
- Enough fuel; and
- Food and water, etc.

There are no accommodation facilities at Lake Ngami and camp was set up in the bush next to the Lake (Fig. 3.5C & Fig 3.7D). Similarly, there are no accommodation facilities on Moonlight Island (Fig. 3.5A). Therefore, in addition to the above-mentioned sampling equipment, microscopes, ethanol, tents, sleeping bags, cutlery, wood, medical aid kits, to mention only a few, had to be taken along. Chemicals needed for the calibration of the Hanna meters and extra batteries had to go with as well. Both boats are usually needed when travelling long distances, because of all the equipment that has to be taken with (Fig. 3.1E). For the trip to Seronga, arrangements had to be made for fuel to be left at Sepopa Swamp Stop, which is more or less halfway. On arrival at Sepopa, the empty cans were offloaded and full cans loaded (Fig. 3.6B), both on the way to Seronga as well as on the way back.

TRIP 1 (DECEMBER 2006) (Fig. 3.4)

During this trip, samples were taken at various locations from Popa Falls, in the Caprivi Strip, to Red Cliffs, downstream of Samochima Lagoon. A total of 71 sites were sampled between 16 and 20 December. Dipsticks were used to get an indication of where microbiological counts were high and where samples should be collected to take back to Bloemfontein for analyses. The dipsticks had to be incubated and an urn was transformed into an incubator, the temperature, of which, was constantly monitored. Based on results from the dipsticks, decisions were made as to where microbiological samples should be collected before departure to Bloemfontein. A trip was made by vehicle to Popa Falls to collect samples there, while the boats were used to access the mainstream, channels, lagoons and floodplains from Mohembo to Red Cliffs. During this trip water levels were higher than in October, but lower than in July. Floods from Angola had not yet arrived in Botswana, but the Delta was receiving local rains as the rainy season in the area of the Delta is between November and March.

TRIP 2 (OCTOBER & NOVEMBER 2007) (Fig. 3.5)

Water was sampled from Mohembo to Moonlight Island (downstream of Nxamasere) as well as at Lake Ngami. The Nchabe River which flows into Lake Ngami was sampled at Toteng. Along the Panhandle, a total of 57 sites were sampled. On the way to Moonlight Island, sampling sites were selected and marked on a GPS and on the way back the following day, samples were collected at the selected sites. At this time, water levels in the Delta were the

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Figure 3.4: Field trip 1. **(A)** Dipsticks used to determine where microbiological samples should be taken. **(B)** Monitoring the temperature in the urn used as a incubator for the dipsticks. **(C)** The ferry at Mohembo. **(D)** Calibration of water meters. **(E)** Taking samples from the boat. **(F)** Taking samples from land at Shakawe. **(A), (B), (D), (E) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

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Figure 3.5: Field trip 2. **(A)** Over-night camp on Moonlight Island. **(B)** Lake Ngami. **(C)** Camp at Lake Ngami. **(D)** Water quality data and zooplankton collection at Lake Ngami. **(E)** Sample collection from a pool in the Nxamasere Floodplains. **(F)** Data collection at Shakawe (Whitey Jordaan). **(D)** Courtesy of the Aquatic Parasitology Research Group, UFS.

lowest as there had been no local rains for months and the flood from Angola had already passed through and had been lost by evapotranspiration.

TRIP 3 (JULY 2008) (Fig. 3.6)

In July 2008, a trip was done by boat down the length of the Panhandle, all the way to Guma Lagoon in the fan-shaped Delta itself. Samples were taken at Popa Falls as well. During this trip a total of 259 samples were taken. Water levels during this trip were the highest. Not only had Botswana received rain between November/December and March, but the trip coincided with the arrival of the annual floods from Angola. As mentioned previously, the maximum aerial extent of flooding in the Delta is from July to August.

TRIP 4 (DECEMBER 2008 & JANUARY 2009) (Fig. 3.7)

As in December 2006, various locations were sampled from Popa Falls to Red Cliffs, but this time water samples were taken at Lake Ngami and the Nchabe River as well. Along the Panhandle, 83 samples were taken. During this trip, water levels were similar to those in December 2006, although the degree of annual flooding had increased, due to an increase in rainfall in the upper catchment area in Angola. Another reason for the slightly higher water level can be because of the fact that this trip was done a few weeks later into the year than in 2006, hence more time was left for local rains to fall.

ALL TRIPS

During each trip, different physical, chemical and microbiological water quality parameters were measured. Physical water quality parameters (temperature, dissolved oxygen concentration, light penetration, conductivity and pH) were tested on site by using portable Hanna meters. The HI 9023 Microcomputor pH Meter, the HI 9033 Multi-range Conductivity Meter and the HI 9143 Microprocessor Auto Cal. Dissolved Oxygen Meter (Figs. 3.4D - F) were used during the first two trips after which the HI 9828 Multiparameter (Fig. 3.6E & Figs. 3.7A - C & E) was purchased and used for the final two trips. The meters were

Figure 3.6: Field trip 3. **(A)** Planning a trip to Seronga by boat. **(B)** Refilling petrol tanks, halfway to Seronga, at Sepopa Swamp Stop. **(C)** Samples collected during trip to, and from, Seronga. **(D)** Guma Lagoon. **(E)** Sample collection at Popa Falls. **(F)** Zooplankton collection at Nxamasere Floodplains. **(A), (C), (E) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

Figure 3.7: Field trip 4. **(A)** Data collection at Popa Falls (Josef Möller) **(B)** Data collection at Nxamasere Lodge, on the banks of the Nxamasere Channel. **(C)** Water quality data and zooplankton collection at the Nxamasere Floodplains (Josef Möller). **(D)** Camp at Lake Ngami. **(E)** Data collection at the Nchabe/Kunyere River, at the old Toteng Bridge (Johan Botha).

calibrated before departure from Bloemfontein and on a regular basis during each trip. Light penetration is an estimation of the water clarity, or the approximate depth to which incident light is able to penetrate the water and was measured by making use of a secchi disk (Figs. 3.5F & 3.6C).

LABORATORY WORK

In addition to the field measurements, 500 ml samples of surface water were collected at selected sampling sites for detailed chemical analysis done by the Institute for Groundwater Studies on the campus of the University of the Free State. Appropriately treated glass bottles, in which water was sampled for bacterial/microbiological water quality, were provided by the Institute before departure to the Okavango Delta. Samples were collected at a number of sites along the panhandle, where human activity and livestock numbers are high. All samples were kept cool, and stored in the dark prior to and during transportation back to Bloemfontein where they were tested for chemical and microbiological water quality parameters. The following parameters were tested for:

Chemical:

- Total Dissolved Solids (TDS)
- Calcium (Ca)
- Magnesium (Mg)
- Sodium (Na)
- Potassium (K)
- Chloride (Cl)
- Fluoride (F)
- Bromide/Bromine (Br)
- Ammonium ions (NH_4^+)
- Nitrite as Nitrogen (NO_2-N)
- Nitrate as Nitrogen (NO_3-N)
- Orthophosphate (PO_4-P)
- Sulphate (SO_4)

- Total Organic Carbons (TOCs)

Microbiological:

- Heterotropfic Plate Count
- Total Coliforms
- Faecal Coliforms
- *Escherichia coli*

The Okavango Delta is a great distance from Bloemfontein (almost 2,000 km) and two days are required to complete the journey. Therefore, although microbiological samples were only collected on the last day of each field trip, it only arrived at the laboratory of the Institute for Groundwater Studies two days after collection. Microbiological analyses should preferably be done within 24 hours after collection and it is, therefore, important to recognize that these analyses are probably not accurate. Despite these potential inaccuracies, the microbiological analyses can be used to provide general indications of the coliform status of the sites where the samples were collected.

COMPUTOR PROGRAMS

A computer program designed to process water quality measures, Windows Interpretation System for the HydroGeologist (WISH) (courtesy of the Institute for Groundwater Studies, UFS), was used to process data and to draw up graphs and figures in order to illustrate results.

The rest of the programs used were standard Microsoft programs (Word, Excel and Publisher), as well as Adobe Photoshop and Illustrator.

ZOOPLANKTON SAMPLES

Zooplankton was sampled using plankton nets of different mesh sizes at many of the sites along the Panhandle and elsewhere, especially at the Nxamasere

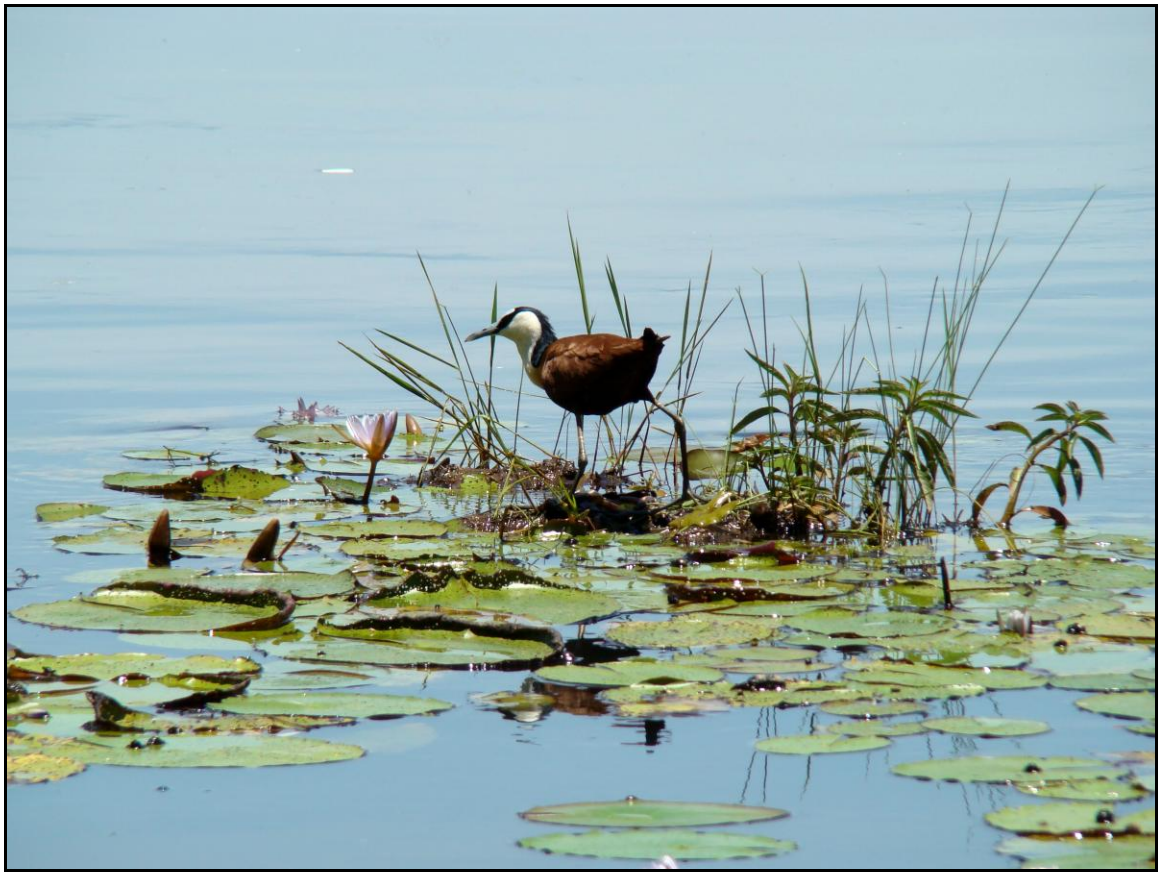
Floodplains (Figs. 3.6F & 3.7C) and Lake Ngami (Fig. 3.5D). During one occasion it was also collected at the Makgadikgadi Pans. The zooplankton was fixed in 70% ethanol and will form part of another project in the near future. Zooplankton has been collected on a yearly basis from Lake Ngami ever since the Lake was inundated again in 2003, after being dry for more than 20 years. This will form part of a long-term study, which aims at determining the succession of zooplankton species in Lake Ngami.

At all sites, biological observations were made and plants, etc., were recorded.

ILLUSTRATIONS AND PHOTOS

Certain figures and photos where used with the courtesy of the Aquatic Parasitology Research Group, University of the Free State. The rest of the photos were taken by the author and fellow students and friends.

Chapter 4



WATER QUALITY: INTRODUCTION, RESULTS AND REMARKS

INTRODUCTION

Worldwide, tremendous pressures are being placed on water resources due to a rapidly increasing human population and the accompanying greater demand for space and development. Water sources are being polluted, the incidence of water-related diseases is increasing and aquatic biota is being lost. According to the Water Research Commission (WRC) (1998), the World Health Organisation considers poor water quality and insufficient sanitation to be the foremost causes of death amongst poor people. The protection of water resources is vital, especially in a land-locked, water-scarce area such as Botswana.

Fresh water aquatic ecosystems can be considered to be "the base from which the water resource is derived". We as human beings rely on a number of services that aquatic ecosystems provide us with. These services are many and the following are some of the more apparent ones:

- Wetlands are able to self-purify to a certain degree;
- It provides us with an aesthetically pleasing environment;
- Water bodies serve as a recreational resource;
- It provides a livelihood to people who depend on the natural environment for food; and
- Wetlands provide habitats to those plants and animals dependent on aquatic ecosystems and, in so doing, they maintain biodiversity (DWAF 1996d).

Therefore, aquatic ecosystems should be effectively protected and managed in order to ensure that southern Africa's water resources remain fit for various uses on a sustainable basis (DWAF 1996d). South African law requires that the country's water resources be protected (National Water Act 1998). Chapter 3 of the National Water Act 36 of 1998 states that: "the protection of water resources is fundamentally related to their use, development, conservation, management and control. Parts 1, 2 and 3 of this Chapter lay down a series of measures which are together intended to ensure the comprehensive protection of all water resources. Parts 4 and 5 deal with measures to prevent the pollution of water resources and measures to remedy the effects of pollution of water resources". In Namibia there is the Water Resources Management Act 24 of 2004. Part XII of this act deals with the protection of water resources, while part XIII deals with water use, conservation and efficient water management practices. However, it does not state that all water resources should be protected, but rather those which are declared a water management area by the minister (Water Resources

Management Act 2004). The water regulation of the Government of Botswana, Chapter 34:01 *Water*, deals mainly with the right to use water. Only in the final section of this chapter it is stated that public water may not be polluted and that the flow of water may not be altered or interfered with.

Aquatic ecosystems include numerous species, habitats and processes, which need to be protected so that healthy ecosystem structure and functioning can be maintained. These species, habitats and processes are all interlinked and interdependent and because of the complex nature of aquatic ecosystems, the effects of water quality changes on specific components may be indirect. A certain fish species, for example, may disappear from a wetland or river, not because this species could not tolerate the change in water quality, but because other fish species or other organisms, which are their primary food source, have disappeared due to the change in water quality (DWAF 1996d).

The term "water quality" is used to describe the microbiological, physical and chemical properties of water. These properties determine if water is fit for use (by not only people, but also by plants and animals) and are controlled or influenced by substances dissolved or suspended in the water (WRC 1998). Water quality investigations provide essential background and contextual information on different aspects of the biodiversity of the Okavango Delta.

MICROBIOLOGICAL QUALITY / INDICATOR ORGANISMS

Microbiological quality refers to the presence of microscopic organisms such as protozoa, bacteria and viruses in water. The most commonly used indicators to determine the microbiological quality of water supplies for domestic use are total coliforms and faecal coliforms, as well as *Escherichia coli* (WRC 1998; Department of Water Affairs and Forestry (DWAF) 1993). Faecal coliform bacteria almost definitely originate from the faeces of warm-blooded animals as well as humans. This can be confirmed if *E. coli* is found to be present (DWAF 1993).

Microbes usually decay when temperatures are elevated, or under too much solar radiation and when there are extremes in pH, while, on the other hand, they easily survive where there are elevated nutrient concentrations and lower temperatures (DWAF 1993). To test for the presence of organisms, which can possibly cause infectious diseases, in water one, or all, of four tests can be done. These include total coliform, faecal coliform, *E. coli* and heterotrophic counts. It is important to understand what each of these counts mean and the target water quality ranges (TWQR) for each can be found in table 4.1.

Total coliforms

Total coliform bacteria are indicative of the general hygienic quality of water and comprise not only bacterial species of faecal origin, but also a number of other bacterial groups (WRC 1998). Bacteria such as *Escherichia coli*, *Citrobacter*, *Serratia*, *Klebsiella*, *Enterobacter*, *Erwinia* and *Yersinia* are all positive for the conventional coliform test, but are not all of faecal origin. Although they are found in high numbers where faecal contamination is present, the use of total coliforms to suitably point out faecal contamination has been criticised. This is because studies on total coliforms have shown that they can be of environmental origin other than faecal sources and therefore, may not be suitable indicators of faecal contamination (WRC 1998; Wutor *et al.* 2009). Pristine surface water usually has bacterial counts of 1 – 10 per 100 ml, while counts anywhere between 100 and 100 000 per 100 ml may be found in polluted water (WRC 1998).

Faecal coliforms

Faecal coliforms, on the other hand, are almost definitely of faecal origin and inhabit the digestive system of warm-blooded animals, including humans. It, therefore, indicates the presence of faecal pollution and, more importantly, may be an indication of disease-causing micro-organisms from the intestines of warm-blooded animals and/or humans. Although not all the micro-organisms found in faecal coliforms are disease-causing, it is a smaller subset than total coliforms and includes less micro-organisms. Yet, both still include disease-causing micro-organisms. According to WRC (1998), counts of 1 – 10 are common in pristine surface waters. On the other hand, polluted water usually contains counts between 10 and 1,000,000 per 100 ml of water.

Escherichia coli

Escherichia coli are a diverse group of bacteria of which most strains are harmless, but some can cause diseases. *Escherichia coli* and enterococci are consistently coupled with faecal pollution and, therefore, most reliably indicate faecal contamination in water (Wutor *et al.* 2009). *Escherichia coli* usually make up about 97 % of the coliform bacteria in human faeces, while the rest includes other *Escherichia* spp., *Enterobacter* spp. *Klebsiella* spp., and *Citrobacter* spp. Some faecal coliform tests also specify *Klebsiella* spp., which can originate from non-faecal sources, as well as a few other bacterial strains which, too, are not of faecal origin. *E. coli* is hardly ever present in soil and water if it has not been exposed to faecal contamination. That is why *E. coli* indicates faecal pollution best (DWAF 1993).

Heterotrophic bacteria

Although heterotrophic bacterial counts do not necessarily represent the total bacterial population present they do indicate the general microbial quality of water and are used to evaluate the effectiveness of water treatment and disinfection processes. This is done in order to test the reliability of distribution systems for after-growth, as well as to determine the quality of water used in industrial processes. In treated water, high heterotrophic plate counts indicate that the water has been treated inadequately, that it was contaminated after treatment or that there was bacterial after-growth in the distribution system. Therefore, pathogenic micro-organisms, bacteria, viruses or parasites may possibly be present in the water. This could pose a serious health risk, should the water be consumed by people (DWAF 1996a).

Only those bacteria which are able to grow under the particular conditions of the test are counted and, therefore, heterotrophic plate counts do not point out possible faecal pollution nor do they represent the total number of bacteria present in the water. Heterotrophic plate counts do, however, detect a wide range of bacteria and are also often referred to as a standard plate count or colony count (DWAF 1996a).

The bacteria detected by heterotrophic plate counts are omnipresent in nature and when water is polluted it may give rise to conditions that are favourable to bacterial growth, such as high nutrient concentrations and high turbidity. This can result in a considerable increase of these naturally-occurring organisms, the activities of which are dependent on the physical, chemical and biological interactions of the aquatic environment. These interactions determine growth rate and survival (DWAF 1996a).

Table 4.1: Microbiological target water quality ranges, as set out in the South African Water Quality Guidelines (DWAF 1996a-d), for various uses.

MICROBIOLOGICAL PARAMETERS	**TARGET WATER QUALITY RANGE (TWQR)**			
	Domestic Use	**Aquatic Ecosystems**	**Aquaculture**	**Livestock Watering**
Total Coliforms	0 - 5 counts/100ml	NA	NA	NA
Faecal Coliforms	0 counts/100ml	NA	NA	0 – 200 counts/100ml
Escherichia coli	NA	NA	Not pathogenic to fish	NA
Heterotrophic Bacteria	0 - 100 counts/ml	NA	NA	NA

NA = Not Available

PHYSICAL QUALITY

Physical quality includes the water quality properties that can be tested by making use of physical methods, including conductivity, pH and turbidity measurements, which mainly influence the taste, odour and appearance of water (WRC 1998). Two other physical properties are not important when considering water quality for human consumption, but are vital to all aquatic life-forms, namely temperature and dissolved oxygen.

pH values

pH is a logarithmic expression of the hydrogen ion concentration in water and indicates whether it is sour or soapy to taste. At $pH < 7$ water is acidic and at $pH > 7$ water is alkaline. Geological and atmospheric influences determine the pH of natural waters.

For surface water, pH values typically range between 4 and 11, while in most unpolluted (raw) waters it lies in the range of 6.5 – 8.5. Values of less than 6.5 can be found where acidification processes take place, such as where there is acid mine drainage. Here pH values may be as low as 3.0. Alkalanisation processes, such as exposing water to lime or other alkalis may increase the pH to more than 8.5 (WRC 1998). Table 4.2 indicates the target ranges of pH for various uses.

The pH of natural waters influences physical, chemical and biological processes in the aquatic environment, while it may be influenced, in turn, by factors and processes such as temperature, nutrient cycling, acid mine drainage, discharge of effluents, runoff and decay processes. The geology and geochemistry of rocks and soils as well as biological activity can also affect pH and the variability of pH in aquatic ecosystems (DWAF 1993).

The pH of a wetland may vary both diurnally and seasonally, diurnal fluctuations occurring in productive systems where the pH values may fluctuate widely, from below 6 to above 10, over a 24-hour period. This is as a result of changing rates of photosynthesis and respiration (DWAF 1996d).

The health effects caused by pH may either be direct or indirect. The direct effects are the irritation and burning of mucous membranes by extremes of pH, while the indirect effects are caused by corrosion products, which form in pots or distribution pipes. This mostly takes place at acidic pH values (WRC 1998). pH is closely associated with other aspects of water quality, therefore, it is difficult to determine if there is a direct relationship between the pH of drinking water and human health. The most important impact of pH in water for domestic use is due to its effects on water treatment, as corrosion in the water supply system is one of the main sources of metal contamination in drinking water. Furthermore, the pH level influences the efficiency of chlorine disinfection, which decreases at high pH values (DWAF 1993).

For treatment purposes the pH is normally adjusted by the addition of alkali reagents such as lime, sodium hydroxide, or sodium carbonate (for pH increase) or acidic reagents such as sulphuric or hydrochloric acid (for pH decrease) (DWAF 1993; WRC 1998).

Changes in pH in aquatic ecosystems directly cause changes in the ionic and osmotic balance of individual organisms. In such instances, the rate and type of ion exchange across body surfaces uses much more energy. This causes, amongst others, slow growth and decreased productiveness (DWAF 1996d).

The tolerance range of most freshwater fish falls between pH 6 – 9, as long as other criteria are the best possible, especially ammonia concentration. When the environmental pH is above or below this range, toxic effects occur from disturbances in internal ion homeostasis. The blood pH is changed, hereby reducing the capacity for ion influx across the gill epithelium and causing fish to lose the ability to control diffusive ion efflux. The final effect is a continuous decline in plasma concentrations of sodium and chloride ions, which are vital for the active transport of excretory products. Therefore, the ability to remove excretory products is affected and these products accumulate, causing the toxic effects (DWAF 1996c).

The toxic effects of **low pH** mainly result from effects on calcium metabolism. The effects caused by acid stress can include an interference with reproductive physiology, which results in reproductive failure, as pH values below 6.5 disturb calcium metabolism. This metabolism controls ovum maturation and, therefore, such a disturbance may cause faulty protein deposition in developing oocytes. Alterations in calcium metabolism may also result in high levels of deformity among developing fish. When fish are exposed to pH levels of less than 5, gill membranes are altered, which results in impaired gas exchange, ion regulation, diffusive loss of ions and excretion. When acid stress is bad, the combined effects of changes in blood chemistry and gill damage causes hypoxia and, eventually, mortality. Under these conditions circulatory failure occurs as arterial blood pressure increases and the affinity of haemoglobin for oxygen is reduced, which results in blood anoxia (DWAF 1996c).

High pH levels reduce the ability to eliminate ammonia, but precisely how ammonia accumulates, is not fully understood (DWAF 1996c).

Electrical conductivity (EC), total dissolved solids/salts (TDS) and salinity

The total dissolved solids concentration is a measure of the quantity of all dissolved compounds in water, while the total dissolved salts concentration is a measure of the quantity of all compounds dissolved in water that carry an electrical charge (DWAF 1996d).

The electrical conductivity (EC) of water indicates the amount of salts present and is, therefore, an indication of the salinity or total dissolved salts (TDS) content (DWAF 1993). TDS and salinity are both measures of the mass of solutes in water, but TDS is the mass of dissolved organic and inorganic matter, while salinity is the mass of dissolved inorganic matter only (DWAF 1996c). Conductivity, on the other hand, refers to the number of ions and is a measurement of the ease with which water conducts electrical current, e.g. distilled water conducts electricity poorly, while sea water is a very good conductor of electricity, because of its high salt content (WRC 1998). Relatively good conductors of electricity are solutions of most inorganic acids, bases and salts, whereas organic compounds either conduct very little or no current at all (DWAF 1993).

Conductivity is a useful surrogate measure of TDS and may be related to the latter by a factor ranging from 5.5 to 7.5 for most natural waters. The mean relationship between TDS and EC is: EC (mS/m) x 6.5 = TDS (mg/L) (DWAF 1993).

The physical and chemical properties of the geological formations through which water flows, determines, to a large extent, the ionic content of that water (DWAF 1996c). Rainwater, for example, has a low EC (<1mS/m) (WRC 1998), but picks up salts as it flows downstream to the ocean. It is the nature of the geology and evaporation (climatic conditions) which determine the salt content at a specific point along the water course.

TDS and EC of waters in areas of granite, siliceous sand and well-leached soil is generally low at less than 30 mg/L TDS or 5 mS/m. Water in contact with precambrian shield areas is intermediate at less than 65 mg/L TDS (< 10 mS/m), while waters of Palaeozoic and Mesozoic sedimentary rock areas have high levels of TDS ranging between 195 and 1,100 mg/L TDS or 30 and 170 mS/m. The major contributing ions are carbonates, chlorides, calcium, magnesium and sulphates, while TDS concentrations can also exceed 1,100 mg/ml as a result of evapoconcentration (DWAF 1993; DWAF 1996d).

Domestic and industrial discharges and runoff cause the elevation of TDS and EC levels in natural waters, while various other factors also influence the EC of water. These include:

- the nature and concentration of solutes in water;
- the extent at which they dissociate into ions;
- the sum of electrical charge on each ion;
- mobility of ions, as well as the water temperature (DWAF 1993).

Evaporation, too, causes an increase in the total salts dissolved in water.

Aquatic organisms possess many different physiological mechanisms and adaptations to sustain the essential balance of water and dissolved ions in the cells and tissues. This is a tremendously important ability when considering the effects that TDS can have on aquatic biota. Changes in TDS concentrations can have an effect on organisms at different levels, namely:

- effects on individual species, as well as adaptations of these species;
- effects on different community structures; and
- effects on processes (microbial and ecological), such as metabolic rates and nutrient cycling (DWAF 1996d).

The rate at which TDS concentrations change and the duration of the change, seems to be more significant than the change itself and organisms which are adapted to wetlands with a low-salinity, are generally sensitive to TDS concentration changes (DWAF 1996d). The target water quality range for all inland waters is stated in terms of case- and site-specific TDS concentrations, which should not be changed by more than 15 % from the normal cycles of the water body under unimpacted circumstances (DWAF 1996d).

Almost all bony fishes maintain body fluids at a constant osmotic concentration of about 10 g/L and are known as osmoregulators. Freshwater fish have a higher concentration of ions in their body fluids than there is in the environment in which they live and, therefore, there is a constant osmotic flow of water into the body and a loss of ions to the surrounding water. Fishes compensate for this by producing large volumes of dilute urine and by absorbing ions from the water, but if the salinity of the environment exceeds the osmotic concentration of the body fluids, the situation is reversed. Water is now lost from the body and ions accumulate (DWAF 1996c).

Species capable of tolerating only limited ranges of salinity are referred to as **stenohaline** and are normally tolerant of salinities up to the iso-osmotic equivalent of the ionic concentration of the body fluids. However, at these salinities survival rates are reduced and depend on water temperature and how well fish can acclimatize. If salinity rises above 5 g/L fish may experience stress, which decreases productivity. Adult and juvenile fish are more tolerant to salinity changes than eggs and larvae and, therefore, high salinities during early life stages may cause increased mortalities and lower growth rates. Metabolic disfunction and mortality occurs due to disruption of homeostatic balance when stenohaline fish are exposed to salinities above 10 g/L (DWAF 1996c).

Euryhaline fish can tolerate salinities above and below the osmotic concentration of their body fluids. Tolerance limits of these fish are greatly influenced by, amongst others, acclimation, life history stage and water temperature. These limits are also species specific (DWAF 1996c).

According to DWAF (1996c), loss of equilibrium and increased respiratory rates are obvious symptoms of osmotic shock. The target water quality ranges vary for different users (Table 4.2).

In humans, physiological effects may be directly related to high concentrations of dissolved salts and an excess of salts negatively affect the kidneys, cause water to have an unpleasant taste and increase scaling and corrosion (DWAF 1993). At levels above 150 mS/m water has a salty taste and above 300 mS/m it doesn't slake thirst, while health effects occur at levels above about 370 mS/m only (WRC 1998). The health effects include:

- laxative effects (when high concentrations of sulphates are present);
- adverse effects on cardiac patients and people who suffer from high blood pressure;
- adverse effects on patients with renal disease, as high concentrations affect kidney function;
- disturbance of salt and water balance in infants and high concentrations of sodium affect women with toxaemia, associated with pregnancy (DWAF 1993; WRC 1998).

Treatment options include energy-intensive processes such as reverse osmosis or electrodialysis, distillation and demineralisation. Large-scale salt removal processes are required with a high level of operator and maintenance skills. Home treatment kits which use ion-exchange processes are available, but are expensive and treat only small volumes (WRC 1998).

Turbidity

Turbidity is used to show the extent to which water lacks clarity and is, therefore, a measure of the muddiness or cloudiness of water and is measured in nephelometric turbidity units (NTU's) by a photoelectric turbidimeter or the depth at which a secchi disk just disappears for an observer above the water. Scientifically, it is defined as the light-scattering ability of water. Clear water has very low turbidity and as the water gradually becomes cloudier, the turbidity increases. The scattering of light in natural waters is due to solids suspended in water (suspensoids), which normally consist of a mixture of inorganic matter, such as clay particles, and organic matter, which usually is both detritus and living organisms (Hart and Allanson 1984; WRC 1998). Micro-organisms are often associated with turbidity and, therefore, the potential for transmission of infectious diseases is directly related to turbidity (DWAF 1993).

Natural processes, such as weathering and erosion, result in large quantities of suspended material, which causes high turbidity. People, too, can cause high turbidity in water bodies by activities such as:

- deforestation;
- poor agricultural practices;
- construction;
- mining operations; and
- discharge of sewage and other wastes (DWAF 1996c).

Some fish species, usually alien species, such as carp, have feeding habits which cause the re-suspension of sediments. Turbidity may differ tremendously from one water body to the next and can range from less than one nephelometric turbidity unit (NTU) (in very clear water) to more than 1,000 NTU (in turbid, muddy water) (DWAF 1996c). The ideal water quality ranges for domestic use and aquaculture are indicated in table 4.2.

Concerning water used for domestic purposes, turbidity does not have direct health effects, but depending on the nature of the origin of the suspended matter causing the turbidity, there may be associated health effects. As stated by DWAF (1993), turbidity significantly affects the microbiological quality of water. In rivers, microbes grow most extensively on the surface of particulates and silt also readily absorbs viruses and bacteria. Furthermore, particulate matter can also protect bacteria and viruses against disinfection. The entrapment of detrimental inorganic and organic compounds, such as nutrients, heavy metals, pesticides and other toxins transported in this form, may be as a result of the absorptive properties of some suspended particles in water. Turbidity may also affect the taste and colour of water.

Other than the health risk turbidity poses to humans, it is of fundamental significance in natural waters. According to Hart and Allanson (1984), it not only affects the visual appearance, but a reduction of solar radiation will reduce the rate of photosynthetic production and the size of the photic zone and influence water temperature and stratification. This reduction in photosynthetic production results in reduced habitat diversity and less food being available. The reduction of macrophytes can have negative consequences as they provide surfaces for bacteria to attach to and, consequently, play an important role in nutrient cycling in freshwater. Furthermore, in highly turbid waters there is always the risk of deoxygenation, because of the presence of high microbiological growth and absorptive silt particles (DWAF 1996c).

Fish species that are tolerant of turbid environments have a number of morphological and physiological characteristics adapted to such environments. These characteristics include:

- circum-oral barbells;
- many sense organs on the body;
- smaller eyes;
- air-breathing organs;
- no bright pigments;
- tolerance to low dissolved oxygen concentrations; and
- gill-cleansing and protecting mechanisms (DWAF 1996c).

Furthermore, such fish are adapted to feeding under conditions of low light intensity and hardly ever rely on vision. They also show adaptations in their breeding biology by having mechanisms to prevent the smothering of eggs by sediments or during low dissolved oxygen conditions (DWAF 1996c).

The breeding behaviour of fish may change in water with high turbidity levels and growth rates may be affected in species which rely on vision to find food. Such predators become less successful in capturing prey in waters with high turbidity and in some instances they stop feeding totally. Eggs and larvae need more oxygen than mature fish and smother more easily. They are, therefore, much more sensitive to turbidity (DWAF 1996c).

Acute effects of turbidity may range from respiratory interference to death, the level of clogging and abrasion of gills determining how toxic the suspended material is. Angular or pointed particles tend to cause the abrasion of gill epithelial tissue and large particles do not clog gills as easily as small particles, which usually clog the primary and secondary lamellae. This results in a reduction of water being circulated through the gills. The damage caused by abrasion may result in the reduced entry of oxygen and may lead to homeostatic failure, blood hypoxia and death. Increased susceptibility to disease may result from a combination of gill damage and elevated stress levels (DWAF 1996c).

Simple filtration or combinations of coagulation, sedimentation and filtration may effectively remove substances causing turbidity from water. The removal of such substances from water relies to a great extent on the characteristics of the suspended solids, which in turn, may be extremely site-specific (DWAF 1993).

Dissolved Oxygen

Gaseous oxygen is generated in water by aquatic plants and phytoplankton during photosynthesis. It also dissolves into water from the atmosphere and is moderately soluble in water. The higher the turbulence of the water, the more rapidly oxygen diffuses into it. The saturation solubility of oxygen in water varies non-linearly with temperature, salinity and atmospheric pressure, as well as with certain other chemicals and physical factors (DWAF 1996d). In other words, when temperature and salinity, for example, increase, the oxygen saturation decreases.

Even though the oxygen concentration in water is not important when considering whether the water is safe for human consumption, it is needed by all aquatic, aerobic organisms for respiration. Therefore, the dissolved oxygen (DO) concentration gives a useful indication of the health of an aquatic ecosystem and the maintenance thereof is of critical importance to ensure the survival and functioning of aquatic biota (DWAF 1996d).

In surface waters that are unpolluted, DO concentrations are close to saturation in almost all cases. At sea level and at TDS values below 3,000 mg/L, saturation concentrations are characteristically: 12.77 mg/L at 5 °C; 10.08 mg/L at 15 °C and 9.09 mg/L at 20 °C (DWAF 1996d), but the ideal ranges for fish and aquatic ecosystems, in general, can be found in table 4.2.

There is a natural 24 hour cycle variation in DO, which is associated with the aquatic biota's cycle of photosynthesis and respiration. Concentrations reach a minimum near dawn, having declined through the night, after which it increases, reaching a maximum by mid afternoon and then decreases again. Seasonal variations are caused by changes in temperature and biological productivity and a reduction in DO concentration may be caused by a number of factors such as:

- river floods or dredging activities may result in anoxic sediments being resuspended;
- anoxic bottom water from a deep lake or water body may be released;
- organic matter which can be oxidized, originates either naturally (detritus) or in waste discharges and the presence thereof can cause a decrease in the DO concentration;
- the saturation concentration of DO is also affected by the quantity of suspended material in the water (DWAF 1996d).

Aquatic organisms experience stress effects when low DO concentrations are combined with high water temperatures or with the presence of toxic substances. The increased toxicity of substances such as zinc, lead, copper, cyanide, sulphide and ammonia has been observed under such circumstances (DWAF 1996d).

When saturation concentrations are less than 100 %, it indicates that DO has been depleted from the theoretical equilibrium concentration, while the super-saturation of oxygen usually indicates eutrophication in a water body. The effects of DO depletion on aquatic organisms depends on the frequency, timing and duration of depletion, such that:

- continuous exposure to concentrations of less than 80 % may have acute effects; and
- physiological and behavioural stress results from repeated exposure to reduced concentrations (DWAF 1996d).

When fish are exposed to low levels of DO they become stressed. This stress causes them to feed less, decreasing growth and production potential and making them more prone to contract infectious diseases. They also show a reduction in egg and sperm viability, as well as impaired gametogenesis. Low DO concentrations may cause fish to swim around faster and more frequently, gulp for air at the water surface and change colour due to stress. Fish eggs and larvae are also affected, as hatching success and survival rates decrease and larvae tend to be deformed (DWAF 1996c).

On the other hand, however, high DO concentrations of more than 20 mg/L are also toxic to fish, causing gas bubble disease and abnormalities in eggs and larvae. In general, the "normal" concentration range is greater than 3 mg/L, the mean concentration being about 5 mg/L. Concentrations between 1 and 3 mg/L are limiting to fish (DWAF 1996c).

The target water quality range, which should protect all life stages of most of southern Africa’s aquatic biota endemic to, or adapted to, aerobic warm water habitats, is between 80 and 120 % of saturation (Table 4.2) (DWAF 1996d).

Temperature

As is the case with dissolved oxygen, temperature, too, is not taken into account when determining whether water is safe for human consumption. However, it does play an important role in aquatic ecosystems. In water, temperature affects the rates of chemical reactions and consequently the metabolic rates of organisms and is definitely one of the major factors controlling the distribution of aquatic biota. Water temperature varies naturally due to seasonal and diel cycles and organisms have evolved to use this as a cue for migration, emergence, spawning, etc. (DWAF 1996d).

Generally, inland water temperatures in southern Africa range from 5 to 30°C and are dependent on various features of the region and catchment area in which they are located. These features are:

- the latitude and altitude of the water body;
- hydrological factors including the water's source, contributions by groundwater, the flow rate and the rate of discharge;
- climatic factors, for example air pressure, air temperature, wind speed, cloud cover and rainfall events; and
- structural characteristics of the river including the catchment area. These include, amongst others, topographic features, density of vegetation cover, depth and volume of water, turbidity and channel structures (DWAF 1996d).

Daily and yearly periodicity patterns are characteristic of surface waters, as well as longitudinal changes along a river course and in deeper waters, vertical stratification. The factors mentioned above also affect the minimum and maximum temperatures, as well as the temperature ranges. Changes in water temperature may also result from a number of anthropogenic sources such as:

- the discharge of heated industrial effluents into a river;
- the discharge of heated effluents from power stations;
- heated irrigation water returned to the system;
- an increase in the amount of solar radiation reaching the water may result from the removal of riparian vegetation cover;
- water transfers between basins; and
- the release of water from impoundments (DWAF 1996d).

An increase in water temperature decreases the solubility of dissolved oxygen, therefore decreasing the concentration of oxygen in water, as well as its availability to aquatic biota. Microbial activity takes place at higher water temperatures and if the organic load into a river or water body is high, oxygen depletion accelerates microbial activity. Furthermore, an increase in temperature increases metabolic rates, meaning that respiration and, therefore, oxygen demand of aquatic organisms is elevated. Consequently, the dissolved oxygen supply decreases (DWAF 1996d).

On the other hand, unnaturally low temperatures may suppress normal activities, such as spawning in fish. As water temperature increases, it intensifies the toxicity of certain substances, as well as the vulnerability of organisms to these substances (DWAF 1996d).

The effects that temperature variations have on aquatic organisms depend on the degree, duration and timing of these changes and large, quick shifts in temperature are lethal to aquatic organisms. Fairly small temperature changes, on the other hand, if maintained for a period of time, may cause community composition to be altered because of the different optimal temperatures of the organisms (DWAF 1996d).

When assessing the effect of water temperature on aquatic ecosystems, one usually considers the acute and chronic physiological effects it may have on organisms. Another thing to consider is the effect that changes from natural site-specific temperature regimes may have. These changes usually result in ecosystem structure and functioning being altered (DWAF 1996d).

Organisms living in water have upper and lower thermal tolerance limits, as well as optimal temperatures for growth and a preferred temperature range. They also have temperature limitations for activities such as migration, spawning and egg incubation. All organisms associated with freshwater, except birds and mammals, cannot control their body temperatures. They are, therefore, totally dependent on, and very vulnerable to, changes in water temperature and rapid changes may severely affect them, resulting in mass mortality. When fish die from acute exposure to elevated temperatures, it is basically as a result of metabolic failures which include:

- a fluid-electrolyte inequality;
- changes in gaseous exchange and osmoregulation;
- central nervous system hypoxia; and
- the deactivation of enzyme systems (DWAF 1996d).

All aquatic ecosystems have their own natural temperature regimes and local conditions (including spatial and temporal variability) should be determined before a water quality objective is made for a specific wetland. Spatial variability includes geographic and longitudinal differences, as well as differences with depth, while temporal variability includes diel and seasonal differences and rapid rates of temperature change. The target water quality range varies between all aquatic ecosystems, but the water temperature should not vary from the background average daily water temperature, calculated to be normal for that specific site and time of day, by more than 2 °C or by more than 10 % (Table 4.2) (DWAF 1996d).

Table 4.2: Physical target water quality ranges, as set out in the South African Water Quality Guidelines (DWAF 1996a-d), for various uses.

PHYSICAL PARAMETERS	TARGET WATER QUALITY RANGE (TWQR)			
	Domestic Use	**Aquatic Ecosystems**	**Aquaculture**	**Livestock Watering**
pH	6.0 - 9.0	Must not change by > 5 % or > 0.5 pH unit	6.5 - 9.0	NA
Electric Conductivity	0 - 70 mS/m	NA	NA	NA
Total Dissolved Solids	0 - 450 mg/L	Must not be changed by > 15 %	Complicated	0 - 1000 mg/L
Turbidity	0 - 1 NTU	NA	< 25 NTU for clear water species	NA
Dissolved Oxygen	NR	80% - 120 % of saturation	5 - 8 mg/L	NR
Temperature	NR	Must not change by > 2°C or > 10 %	Complicated	NR

NA = Not Available. NR = Not Relevant.

CHEMICAL QUALITY

The chemical quality of water refers to the nature and concentration of substances dissolved in the water, such as salts, metals and organic chemicals, many of which are needed in our daily intake. At high concentrations, however, these chemical substances make water unpalatable and cause sicknesses (WRC, 1998). Throughout the world, concentrations of nutrients such as nitrogen and phosphorus have increased considerably in rivers, causing eutrophication, harmful algal blooms and high levels of nitrate and phosphate (Postel 2007). In the Okavango Delta, all of the tourism operators have located their establishments or accommodation facilities close to the main river, side channels or lagoons and it is ,therefore, highly possible that nutrients and salts from sanitation systems are spilling into the waterways. All of the tourism operations visited by the Water Quality Team of the AquaRAP biodiversity survey of the Okavango Delta (Alonso and Nordin 2003) made use of septic tanks and soak-away systems in the Kalahari Sands. According to Alonso and Nordin (2003) the sand is very permeable and salts and nutrients (especially nitrogen) can pass through it easily. They strongly recommend that the authorities make sure that all tourism operators properly design and construct such septic tank sanitation systems, so that effluent flows away from the open waters.

In industrial countries, and increasingly in the developing world, water sources are being contaminated by chemicals, such as those from pesticides and industrial and military discharges (Postel 2007). When pesticide levels are too high in rivers and streams, they are harmful to aquatic life and fish-eating wildlife. According to Alonso and Nordin (2003), a 25-hectare area of irrigated agricultural land is situated on the west bank of the Okavango River at Samochima Village downstream from the town of Shakawe. This agricultural land is situated next to a side channel from which irrigation water is drawn. The crops grown here consist of a variety of vegetables intended for the local market and are irrigated by a centre-pivot overhead spray system. The irrigation pump house is situated a few meters from the channel bank and the tank in which agro-chemicals, like various fertilizers and pesticides, are mixed is situated next to it. Alonso and Nordin (2003) claim that there were clear signs that chemicals had been spilt onto the ground and had washed into the channel and that no attempts appeared to have been made to prevent the inflow of these chemicals to the channel. It is highly unlikely that the farm’s management would have cleared up their act and these chemicals, whatever their nature, will have a negative effect on the water quality of the channel. In addition, Alonso and Nordin (2003) also state that some of the water used for irrigation will also enter the local ground water and flow back towards the river channel rapidly, given the sandy soils of this area.

The presence of many chemicals can be tested for when determining the chemical quality of water. Only those chemicals tested for during our research on the water quality of the Okavango Delta will be discussed here. These include the chemicals most commonly known to cause water quality problems in surface water in southern Africa. The chemicals which were not tested for (e.g. iron and manganese) are irrelevant to this study, as they are commonly found in groundwater.

Home treatment kits are available for a number of chemicals such as fluoride, calcium, magnesium, sodium, chloride and potassium, but they are expensive and only treat small volumes of water (WRC 1998).

Fluoride (F)

Fluoride is the most electro-negative element and easily forms complexes with a number of metals. A small amount is needed during tooth formation to harden dental enamel and to increase resistance to attack on tooth enamel by bacterial acids. Fluoride is present in many foods and the water that we drink is estimated to contribute between 50 % and 75 % of the total dietary fluoride intake in adults (DWAF 1993; WRC 1998).

In unpolluted surface water fluoride concentrations are usually between 0.1 and 0.3 mg/L (WRC 1998). The optimum concentration of fluoride in water depends on water consumption and, hence, air temperature, because the hotter it is, the more water is consumed (DWAF 1993).

Fluorine is a fairly common element. It makes up more or less 0.3 g/kg of the earth’s crust and exists as fluorides in a number of minerals. Fluorides are also present in numerous industrial products such as phosphate fertilizers, bricks, tiles and ceramics, as well as in a wide range of pharmaceutical products and occasionally enters rivers due to industrial discharge (DWAF 1993).

In humans, high doses of fluoride interfere with carbohydrate, lipid, protein, vitamin, enzyme and mineral metabolism and can damage the skeleton, causing bones to harden and making them brittle when concentrations of fluoride in water exceed 3 to 6 mg/L. Brittle bones break easily under mild stress and crippling can occur at intakes of 20 to 40 mg per day. People with renal disorders may experience chronic effects on the kidneys, as well as less common problems, such as effects on the thyroid. Acute toxic effects may also occur such as haemorrhagic gastroenteritis, acute toxic nephritis and injury to the liver and heart muscles, many of which are associated with fluoride's binding of calcium. Even at high concentrations, fluoride cannot be detected aesthetically as it has no taste, colour or smell, but one will know if high doses have been consumed as initial symptoms of fluoride toxicity such as vomiting, abdominal pain, nausea, diarrhoea and convulsions may set in (DWAF 1993; WRC 1998).

Not only in humans, but in all mammals, low concentrations of fluoride (< 1 mg/L) strengthen tooth enamel and bones, while exposure to intermediate fluoride concentrations over long periods may cause skeletal fluorosis. In the Kruger National Park, for example, isolated observations revealed that Hippos that have been exposed to fluoride concentrations higher than 4 mg/L, developed different signs of bone and tooth enamel fluorosis. In certain areas it may be necessary to modify fluoride criteria, but the typical target water quality range for aquatic ecosystems is less than 0.75 mg/L (Table 4.3) (DWAF 1996d).

Fluoride is difficult to remove from water at low concentrations, but at concentrations above 20 mg/L it can be removed fairly easily by making use of lime and/or alum treatment. At lower concentrations advanced treatment is required such as ion-exchange adsorption and reverse osmosis (DWAF 1993).

Calcium (Ca)

Calcium, an alkaline earth metal, reacts with water to form calcium hydroxide, otherwise known as slaked lime, and is important for building and maintaining a healthy bone structure. Rain water (or soft waters) usually has calcium concentrations of less than 10 mg/L, whereas in groundwater (or hard waters), calcium concentrations may be several hundred mg/L. In such hard waters, calcium can make up a significant proportion of a person's required daily intake. Humans and animals require large amounts of calcium and at concentrations normally found in surface water, it has beneficial health effects (WRC 1998).

The consumption of very high concentrations of calcium may lead to sensitive individuals developing kidney stones. Furthermore, elevated concentrations of calcium may cause water to taste "hard", although it generally imparts a pleasant taste to water. At high concentrations, calcium, together with magnesium, causes scaling in distribution systems and appliances, whereas soft waters (in which calcium is absent or in very low concentrations), may cause corrosion (WRC 1998). The target water quality range for calcium is given in table 4.3.

Calcium can be removed from drinking water by demineralisation techniques such as ion exchange or by cation exchange softening, but chemical precipitation and sedimentation are most often used to treat large volumes of water (WRC 1998).

Magnesium (Mg)

Magnesium, too, is an alkaline earth metal which is an essential nutritional element needed for muscles to function normally. It burns with luminous light to form magnesium oxide and is, therefore, used in flares. Magnesium hydroxide is a stomach antacid in the form of Milk of Magnesia and as magnesium sulphate ('Epsom salts'). The concentration of magnesium in unpolluted fresh water commonly is less than 10 mg/L, while in hard groundwater, concentrations of magnesium may be as high as several hundred mg/L. Adults need to consume more or less 250 mg of calcium daily (WRC 1998).

According to WRC (1998), because magnesium has a bitter taste, people are discouraged from consuming water in which there are high concentrations and, therefore, there are rarely cases in which people suffer from health effects caused by the ingestion of large amounts of magnesium. These health effects include the suppression of the central nervous system, while the most common effect is diarrhoea, where magnesium is found with sulphate. Above 70 mg/L magnesium imparts a bitter taste to water and, as mentioned previously, at elevated levels (together with calcium) causes scaling in distribution systems and appliances. The target water quality range, however, is between 0 and 30 mg/L (Table 4.3).

The usual method used for treating water with elevated magnesium levels is lime softening followed by re-carbonation, while other treatment options such as the use of ion-exchange resins and the precipitation of the magnesium at high pH can also be used (WRC 1998).

Sodium (Na)

Sodium is an alkali metal, a constituent of table salt (sodium chloride) and an important element in our daily diet, as it helps maintain electrolyte balance in the body. Concentrations of sodium vary a lot in water, both over time and space. In regions where rainfall is high and water is fresh, sodium concentrations are usually less than 50 mg/L, while concentrations can be as high as 500 mg/L in areas with low rainfall (WRC 1998). Ideally, in water set aside for domestic use, sodium concentrations should not exceed 100 mg/L (Table 4.3).

The principal effect of sodium at concentrations usually found in fresh water is aesthetic, because sodium chloride gives water a salty taste. However, excessive intake of sodium salts can place strain on the kidneys and hearts of babies and may lead to serious disturbances of the salt balance in the body, with water retention in individuals with congestive heart failure, kidney disease or high blood pressure (WRC 1998).

Desalination processes such as reverse osmosis or electrodialysis, ion-exchange demineralisation and distillation can remove sodium from water, but these treatment options require high levels of operator skills and maintenance and the processes are easily ruined by suspended matter, and are easily scaled by hard waters (WRC 1998).

Chloride (Cl)

Chloride is the anion of elemental chlorine, which seldomly occurs in nature, but is usually found as chloride. Chloride is the negatively charged component of table salt, which, at high concentrations, accelerates metal corrosion and gives water a salty taste. Chloride concentrations are typically less than 10 mg/L in freshwater and at these concentrations do not cause health effects. Concentrations higher than the typical concentrations of freshwater are found where there is salt pollution or marine intrusion and in dry areas with saline soils, chloride concentrations of up to 700 mg/L are not unusual (WRC 1998).

Fortunately, health effects only occur where concentrations are more than 1,200 mg/L. These health effects include nausea and vomiting in some infants under the age of one year and individuals with congestive heart failure or hypertension who have been placed on a salt restricted diet, as it disturbs their salt/water balance (WRC 1998).

Blue-green algae are least sensitive to chlorine, while green algae are slightly more sensitive and diatoms most sensitive. Fish eggs are less sensitive to chlorine than newly hatched fish larvae and adverse effects have been observed in fish exposed to chlorine. These effects include:

- avoidance behaviour;
- changes in blood chemistry;
- gill damage;
- inhibited growth rate;
- restlessness preceding loss of equilibrium; and

- death (DWAF 1996d).

Chloride, on the other hand, is not considered to be a problem in inland waters, as it has little effect on fish health or behaviour, but at high concentrations near the coast, some freshwater fish may show symptoms similar to those for salinity (DWAF 1996c). Invertebrates are sensitive to chlorine and may become immobile, have a lower survival rate and show evidence of reduced reproduction, while aquatic plants may become chlorotic. Phytoplankton experience reduced rates of photosynthesis and respiration (DWAF 1996d). The ideal ranges for chloride are different for various users (Table 4.3).

Chloride is difficult to remove from water and requires energy-intensive processes which demand high operator skills and maintenance. These processes include reverse osmosis, electrodialysis, distillation or resin ion-exchange demineralisation and are easily contaminated by suspended matter or hard water and which produce a concentrated brine, which can not easily be disposed of (WRC 1998).

Potassium (K)

Potassium is another one of the alkali metals, which is an essential dietary constituent and can be found in typical concentrations of between 2 and 5 mg/L in freshwater (WRC 1998), concentrations well within the target range (Table 4.3). These concentrations are increased when runoff from irrigated lands, fertilizer production and domestic wastes are allowed to enter the water body.

Potassium is the main intracellular, positive ion in living tissues and sudden exposure to high concentrations can badly disrupt muscle and heart function, irritate mucous membranes and cause nausea and vomiting in infants under the age of two years and in people with kidney disease. Although potassium does not affect the appearance or smell of water at elevated concentrations, it does give it a bitter taste (WRC 1998).

Desalination processes are used to remove potassium from water. The removal of this alkali metal from water is difficult and all the processes result in a concentrated waste stream, which may be difficult to dispose of (WRC 1998).

Bromide (Br)

The oceans are the largest natural sources of bromine and chlorine and contain about 65 mg/L of the former. However, in freshwater rivers and lakes, levels of bromine are extremely low (Song and Muller 1993). Bromide is a key element, which is usually present in evaporite deposits. It is, therefore, found in water containing traces of sodium in the form of sodium chloride, sodium bicarbonate and sodium sulphate, etc.

In a study conducted on South Australian freshwaters from a wide variety of environments, Magazinovic *et al.* (2004) found that bromide concentrations correlated linearly with the concentrations of both chloride and TDS. This linear relationship means that chloride data can be used successfully to estimate bromide concentrations. However, an even better estimate of bromide concentrations can be made by using TDS data, as there was a better correlation with TDS. TDS concentrations are easier to measure and extensive historical data exists for many water bodies.

Canton *et al.* (1983) tested the toxicity of sodium bromide for certain freshwater algae, crustaceans and fish and found that the acute toxicity varied from 44 to 5,800 mg Br^-/L (EC_{50} values), depending on the species. Bromide ion distinctly impaired the reproduction of both crustaceans and fish and based on the weakest reproductive performance they proposed a criterion for water quality of 1 mg/L. Concentrations of bromide in surface water regularly surpass this value, at times reaching levels which have acute effects on water organisms.

Since no information or recommendations are given on bromide in the Water Quality Guidelines for South Africa, that proposed by Canton *et al.* (1983) will be used for the purpose of this study.

Nitrite (NO_2) & Nitrate (NO_3) as Inorganic Nitrogen (N)

All the major inorganic nitrogen components present in water such as NH_3, NH_4^+, NO_2^- and NO_3^- are included in the term inorganic nitrogen, in other words, the individual concentrations of ammonia, nitrite and nitrate are added together in order to obtain the inorganic nitrogen concentration. The dissolved forms of inorganic nitrogen as well as those adsorbed onto suspended inorganic and organic material are included because of the fact that they are all available for uptake by algae and higher plants. Inorganic nitrogen has a stimulatory effect on aquatic plant growth and algae and, therefore, it is of great concern (DWAF 1996d).

Ammonia is a reduced form of inorganic nitrogen and nitrite and nitrate are the intermediate and end-products, respectively, of the oxidation of organic nitrogen and ammonia and of nitrification and dentrification. For example, during nitrification, ammonia is oxidised to nitrite which is then further oxidised to nitrate. These conversions of inorganic nitrogen from one form to the other are part of the nitrogen cycle in aquatic ecosystems (DWAF 1996c; DWAF 1996d).

Nitrite and nitrate can easily be converted from one form to the other by bacterial processes, although nitrate is the more stable of the two and is usually much more abundant in aquatic ecosystems (DWAF 1996d; WRC 1998). When conditions are aerobic, nitrite is oxidized to nitrate by nitrifying bacteria, while nitrate is reduced to nitrite and finally to nitrogen by denitrifying bacteria, under anaerobic conditions (DWAF 1996d).

The major sources of inorganic nitrogen entering aquatic ecosystems are:

- surface runoff from surrounding catchment areas;

- effluent streams containing human and animal excrements being discharged into aquatic systems;
- fertilizers from agricultural lands; and
- industrial organic wastes (DWAF 1996d).

In basins that are greatly affected, it is likely that the inorganic nitrogen arising from human activities will well exceed “natural” concentrations. Furthermore, during the decomposition of organic material, many forms of bacteria are able to convert organic nitrogen to inorganic nitrogen (DWAF 1996d).

Inorganic nitrogen is hardly ever present in high concentrations in unspoilt surface waters because it is rapidly taken up by aquatic plants and changed into proteins and other organic forms of nitrogen, within the cells of the plant. Inorganic nitrogen concentrations in aerobic surface waters of southern Africa, which have not been impacted, are usually below 0.5 mg/L. This may, however, increase to above 5 to 10 mg/L in waters which are greatly enriched (DWAF 1996d).

Water temperature, oxygen availability and pH all affect the rate at which the following processes occur:

- ammonification;
- nitrification;
- dentrification; and
- the active uptake of nitrate by algae and higher plants (DWAF 1996d).

Nitrate should make up more than 80 % of the inorganic nitrogen present in unimpacted waters, with a dissolved oxygen concentration between 80 and 120 % saturation. In such instances, ammonia concentrations will be less than 20 % of the nitrogen present or below 0.1 mg/L. Trophic status changes, along with algae and other aquatic plant growth, are usually used to measure the effects inorganic nitrogen has on aquatic ecosystems (DWAF 1996d).

When assessing the influence of inorganic nitrogen on eutrophication, site-specific conditions are vitally important, particularly the availability of phosphorus. Inorganic nitrogen toxicity is considered unimportant when setting inorganic nitrogen water quality guidelines for the safeguarding of aquatic ecosystems. While inorganic nitrogen concentrations of less than 0.5 mg/L are low enough to limit eutrophication and to reduce the probability of blue-green algae and other plant growth, in the presence of enough available phosphorus, nitrogen-fixing organisms will be able to compensate for any deficit caused by low inorganic nitrogen concentrations, by fixing atmospheric nitrogen (DWAF 1996d).

Some distinctive symptoms are coupled with selected ranges of average summer inorganic nitrogen concentrations, provided that all other nutrients and environmental conditions are within favourable ranges for the organisms concerned (DWAF 1996d). The inorganic nitrogen concentrations for a specific system should be based on the existing trophic status of that system and a target water quality range should be derived only after case- and site-specific studies (Table 4.3) (DWAF 1996d).

Phosphate (PO_4)

Elemental phosphorus does not occur in the natural environment, but in water it is usually present as phosphate which is a generic term for the oxy-anions of phosphorus. It occurs as dissolved and particulate species in a number of organic and inorganic forms such as orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates. Of these, orthophosphate is the phosphorus which is immediately available to aquatic organisms, as natural processes can transform it into an available form (DWAF 1996d).

The forms of phosphorus in water are constantly changing and the exchange of phosphorus between sediments and water influences the phosphorus cycle. This exchange, in turn, is influenced by factors such as mineral-water equilibria, water pH values and the activities of living organisms, amongst others. Furthermore, the flow regime of a river also plays a major role in the spatial distribution of phosphorus as well as in the mobility and availability thereof. Phosphorus is removed from the water column to sediments when particulate matter settles on the stream bed, which acts as a sink for phosphorus during low discharge periods. Aquatic biota take up phosphorus, further removing it from the water. During rainy seasons when flow rates are high, phosphorus concentrations in the water column increase. This may be due to runoff from the land, and re-suspension and flushing of deposited material from the river bed to the water column (DWAF 1996d).

Phosphorus enters surface waters naturally by the weathering of the rocks over which the water flows, as well as the subsequent leaching of phosphate salts. The decomposition of organic matter also produces phosphorus in surface waters. High variations in phosphorus concentrations occur from place to place, depending on regional geological characteristics, increasing from mountainous regions of crystalline rocks to lowland areas of sedimentary deposits (DWAF 1996d). Furthermore, there are considerable quantities of phosphate in sewage, because of the high concentrations found in animal and human excretions (DWAF 1996c).

Unnatural sources of phosphorus in aquatic ecosystems are domestic and industrial effluent discharges, atmospheric precipitation, urban runoff and agricultural drainage containing fertilizers (DWAF 1996d). High quantities of phosphate are used as fertilizers in agriculture and, therefore, runoff from farm lands is most likely very rich in phosphate (DWAF 1996c).

Phosphate is a basic component of living tissues and phosphorus is an important macronutrient which plays a vital part in building nucleic acids and storing and using energy in cells. It is, therefore, an essential dietary requirement of all biota and is accumulated by a diversity of living organisms and is readily used by plants in unimpacted waters. In aquatic ecosystems, phosphorus is probably the main nutrient determining the level of eutrophication. Therefore, in order to estimate the effects inorganic phosphorus has on aquatic ecosystems, changes in trophic status and the growth of algae and other aquatic plants must be taken into account (DWAF 1996d).

The existing trophic status of a particular system plays a major role in what the inorganic phosphorus concentration should be, as the concentration must be based on this status. Inorganic phosphorus levels should not be allowed to rise to a level at which it will change the trophic status of a system (Table 4.3) (DWAF 1996d). Generally, in surface waters, nutrient-enriched waters have phosphate concentrations of 0.3 mg/L or more, while unpolluted water may have concentrations as low as 1 µg/L (DWAF 1996c).

Both phosphorus and nitrogen play a role in determining plant growth and the addition of these substances to a water body results in an excessive growth of plants and other organisms, leading to eutrophication and increased biological oxygen demand. This is the most noteworthy effect of elevated phosphorus levels which may vary seasonally because of the growth of aquatic plants (DWAF 1996d; DWAF 1996c).

In fish, poor appetite and the depression of growth are a clear indication of a phosphorus shortage and reduced bone calcification and cranial and skeletal deformities can occur in some species. Fish require phosphate in the diet, but intake exceeding between 0.42 and 1.09 % is directly excreted. Phosphorus from plants is not as available as that from animals, thus the source of dietary phosphorus is important. Dissolved phosphates from natural origins are thought to be mostly non-toxic, but some organophosphates made by man do have toxic effects. It must not be forgotten, however, that the likelihood remains for osmotic stress to result from high concentrations of dissolved phosphate, as is the case with nitrate (DWAF 1996c).

Sulphate (SO_4)

Sulphate is the oxy-anion of sulphur in the +6 oxidation state and arises from the suspension of mineral sulphates in soil and rock. It forms salts with an assortment of cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium and is commonly found in water. When added to water, sulphates tend to accumulate to gradually increasing concentrations. This is because the majority of sulphates are soluble in water (DWAF 1996a).

The concentration of sulphate in unpolluted, fresh, surface water is typically less than 10 mg/L (normally 5 mg/L), but concentrations of several hundred mg/L could occur. This takes place where sulphate minerals dissolute. Sulphates which are discharged from acid mine wastes and many other industrial processes may also raise sulphate levels in water (DWAF 1996a).

At elevated concentrations (200 - 400 mg/L), sulphate imparts a distinctive, slightly bitter or salty taste to water, depending on whether it is principally associated with sodium, potassium, calcium or magnesium. Therefore, the target water quality range for domestic use is below 200 mg/L (Table 4.3). Hydrogen sulphide may be associated with sulphate and there may be a “rotten egg” smell where it is present. Iron, in particular, is eroded when exposed to elevated concentrations of sulphate (DWAF 1996a; WRC 1998).

In humans, high concentrations of sulphate exert acute health effects, such as diarrhoea, especially in users not used to consuming elevated sulphate concentrations. The health effects are temporary and reversible, since sulphate is rapidly excreted in the urine and adaptation tends to occur in individuals exposed to elevated sulphate concentrations in their drinking water for long periods. At sulphate concentrations of 600 mg/L and more, most individuals experience diarrhoea and do not adapt (DWAF 1996a; WRC 1998).

In livestock, sulphate can cause diarrhoea and reduced productivity and growth in young animals as well as in animals that have not previously been exposed, depending on the species, age and adaptation period of the animal and the principal cations associated with the sulphate ion (DWAF 1996b).

Sulphate can be removed from water by processes such as ion exchange, any desalination technique and precipitation with calcium salts, which all require lofty levels of design, operator and maintenance skills. On a household scale, small volumes of water can be produced for drinking by using disposable treatment kits which use ion exchange processes (DWAF 1996a; WRC 1998).

Total Organic Carbons (TOCs)

Only dissolved organic carbon (DOC) (organic carbon present in water in the dissolved form) is discussed in the water quality guidelines for South Africa, but related to it is:

- chemical oxygen demand (COD) which is a measure of the oxygen required by organic matter;
- biological oxygen demand (BOD), a measure of the biochemically-mediated oxygen demand of water which points out the part of the organic carbon which is fairly easily oxidised by micro-organisms; and
- total organic carbon (TOC), which is a measure of the dissolved and suspended organic carbon (DWAF 1996a).

To obtain COD and BOD values, unfiltered water samples are used and, therefore, they are measures of organic matter dissolved and suspended in water. TOC is the sum of dissolved and suspended organic carbon in water (DWAF 1996a) and, therefore, should give an indication of the DOC as well. Table 4.3 indicates the target water quality range for TOC.

DOC concentrations range from being non-toxic to extremely toxic, depending on the origin of the source. When DOC originates from natural humic acids of soil origin, for example, it is usually harmless and only of aesthetic concern, but if the DOC content includes synthetic organic compounds it may be considerably toxic. Synthetic organic compounds can be found in agricultural runoff after the use of pesticides. This is not the only addition to water that affects the character of the DOC, industrial effluents and domestic runoff do as well. In unpolluted water, the DOC concentration is characteristically less than 5 mg/L, but it can rise to much higher levels in waters in which organic wastes are being spilled from runoff (DWAF 1996a).

Although the DOC concentration in water has no direct health implications, the norms for DOC are only given in the guidelines for domestic use and apply mainly to water that has already been treated for human consumption. DOC levels indicate the organic material content of the water which may possibly move across the water treatment process to the stage of disinfection. Should chlorination be used to disinfect water, the DOC concentration may possibly indicate the chances of trihalomethane (THM) formation. Due to their carcinogenic potential, THMs are detrimental in water, but no direct correlation between their occurrence and the DOC, TOC, COD or BOD concentrations can be made (DWAF 1996a).

Treatment is not needed when one has consumed water with high DOC concentrations, unless, however, there were toxic organic substances or sewage present. The presence of DOC can affect the taste, odour and colour of water. It is best to avoid ingesting water high in THMs for extended periods, if possible (DWAF 1996a).

Organic carbon can be removed from water by methods such as filtration, coagulation, flocculation, clarification and oxidization, assuming the residual concentrations only slightly exceed the levels acceptable for domestic use. The strong oxidizing agents used are harmful if not handled properly and in many instances, a combination of treatment processes is needed to achieve the required water quality. In households, the organic carbon concentration of water can be brought down by filtering the water through disposable activated carbon cartridges (DWAF 1996a).

RESULTS AND REMARKS OF STUDY

HETEROTROPHIC BACTERIA

All microbiological test results were extremely high, far above the target water quality range for domestic use. Heterotrophic bacteria at OR36 (Seronga) and SwampStop (mainstream in front of Sepopa Swamp Stop) (Figs. 3.2 & 3.3) were found to be more than 2,500 counts per 1 ml of water (Table 4.4). Both samples were collected in July 2008. The guideline for domestic use states that such counts should not exceed 100 per 1 ml of water. Although heterotrophic plate counts represent naturally occurring organisms and only indicate the general microbial quality of water, high counts may mean that pathogenic micro-organisms, bacteria, viruses or parasites are present in the water. Therefore, water with high counts, such as those at Sepopa and Seronga, could pose a serious health risk if consumed by people.

TOTAL COLIFORMS

The guidelines for domestic use recommend that total coliforms not be higher than 5 counts/100ml. However, at SL2 (Samochima Lagoon), OR55 (from the ferry at Mohembo) and OR61 (mainstream bordering Shakawe) (Figs. 3.2 & 3.3) total coliforms were found to be 119, 579 and 1,733 counts/100ml, respectively (Table 4.4). All three sites were sampled in July 2008. It is interesting to note the difference in total coliform counts between Mohembo and Shakawe as both samples were collected in the mainstream and not in floodplains. Concerning total coliforms, the water at these three locations are far from pristine, as pristine surface water may contain bacterial counts of 1 – 10/100 ml. Based on the results obtained the water can rather be considered to be polluted as such water often contains counts in the range of 100 – 100,000/100 ml. These results indicate that the water at the specific sites is not suitable for human consumption and more information is provided under faecal coliforms.

FAECAL COLIFORMS

Samples were taken to test faecal coliforms at ten different sites along the Panhandle. These locations include both sites of heavy human and livestock activities, as well as sites distant from such activity. The sites with heavy activity include Shakawe floodplains (OR77, December 2006), Sepopa Swamp Stop (SwampStop, July 2008), Seronga (OR36, July 2008) and two sites at the fisheries of Samochima Village (Figs. 3.2 & 3.3), one within the floodplain area (OR141, November 2007) and one in the mainstream (OR121, December 2006). Another three samples were taken in Samochima lagoon along the side where people bath and wash clothes (OR90, November 2007), in front of a homestead (OR92, December 2006) and in the centre of the lagoon (OR93, December 2006). The results obtained ranged from 3 counts/100ml, in the mainstream in front of the fisheries, to 1553 counts/100ml in the Shakawe floodplains. The two samples taken distant from human and livestock activities both showed 5 counts/100ml (Table 4.4). These two locations are situated in Pelican Lagoon (OR81, December 2006) and in the mainstream between Samochima Lagoon and Red Cliffs (OR82, December 2006).

Faecal coliforms are almost definitely of faecal origin and, therefore, indicate the presence of faecal pollution. In pristine surface waters counts of 1 to 10 per 100ml of water are common. The samples collected distant from human activities, being 5 counts/100ml, are, therefore, similar to that of usual pristine surface waters. The water in the mainstream in front of Samochima's fisheries also had a low count of faecal coliforms (3 counts/100ml). Polluted water, on the other hand, can contain counts anywhere in the range 10 – 1,000,000 organisms per 100 ml of water, depending on the degree of contamination. This was the case with the rest of the sites sampled that were close to humans and livestock. Such high counts are detrimental if consumed and further testing of the water is important as many people collect water directly from the river in buckets, especially from Samochima Lagoon.

ESCHERICHIA COLI

The presence of *Escherichia coli* was tested for at all the sites tested for heterotrophic bacteria, total coliforms and faecal coliforms. Counts ranged from 2 to 20 counts/100ml, the lowest being that obtained in the mainstream in front of Samochima's fisheries (OR121) (Figs. 3.2 & 3.3) and the highest in the floodplain area of the fisheries (OR141) (Fig. 5.2C) (Table 4.4). Human activity here is high as boats are launched from this site and people are often seen bathing or swimming in the floodplain area. A large number of cattle are usually present, walking knee-deep in the water and mud. Other counts of two single samples were much higher than the rest. These were 79 and 365 counts/100ml and were obtained in Samochima Lagoon where people bath and wash clothes and in the floodplains at Shakawe, respectively (Fig. 5.2D) (Table 4.4). Human numbers are high at these two villages which are not recognised as official towns (see chapter 5) and, therefore, do not receive the sanitation facilities needed. The reason why counts are usually higher in the floodplains than in the mainstream is because the strong current in the mainstream washes bacteria and other substances away.

GENERAL MICROBIOLOGICAL WATER QUALITY

The results obtained for heterotrophic counts, total coliforms, faecal coliforms and *Escherichia coli* are all above the target water quality ranges, although some results are normal for unimpacted surface waters. The general impression this gives is that the water of the Okavango Panhandle, at least at these specific sites, is not safe for human consumption without prior, proper treatment. It must, however, be kept in mind that samples were only tested at least two days after collection, due to the long distance between Bloemfontein and the Okavango Delta. Water should be tested within twenty-four hours after collection and these

Table 4.4: Study results for microbiological water quality parameters at various sites along the Okavango Panhandle.

SiteName	Site Description	Date &Time	Heterotrophic Plate Count (cfu/ml)	Total Coliforms (cfu/100ml)	Faecal Coliforms (cfu/100ml)	*E. Coli*
OR121	Fisheries	20061220 10:20			3.00	2.00
OR36	Seronga	20080706 12:00	>2500		19.00	4.00
OR82	Mainstream btw Samochima lagoon and Redcliffs	20061220 13:00			5.00	5.00
OR81	Pelican Lagoon	20061220 12:40			5.00	6.00
SL2	Samochima Lagoon	20080720 15:19		119.00		6.00
OR55	Mohembo (at Ferry)	20080713 17:59		579.00		12.00
SwampStop	Sepopa Swampstop	20080707 13:31	>2500		13.00	13.00
OR93	Samochima Lagoon (middle)	20061220 13:21			18.00	14.00
OR92	Samochima Lagoon (Tannie Pollie)	20061220 13:30			18.00	15.00
OR61	Shakawe (mainstream)	20080715 14:26		1733.00		18.00
OR141	Fisheries (where water flows into flooded area from mainstream)	20071102 14:25			727.00	20.00
OR90	Samochima Lagoon (where people bath)	20071103 17:06			308.00	79.00
OR77	Shakawe floodplains	20061219 12:38			1553.00	365.00
TWQR		**Domestic use**	**0 - 100 counts/ml**	**0 - 5 counts/100ml**	**0 counts/100ml**	**NA**
		Livestock Watering	**NA**	**NA**	**0 - 200 counts/100ml**	**NA**

NA = Not Available

results are, therefore, not a perfect indication of the microbiological quality of the Panhandle's water.

pH

The pH of the river, channels, lagoons and floodplains of the Okavango Delta Panhandle for all four trips fell within the range of 6.09 to 7.38 (Fig. 4.1). The highest pH values of 7.21, 7.37 and 7.38 were recorded at Samochima Lagoon although the pH values at Popa Falls and at the Nxamasere Floodplains (Fig. 3.2) were even higher. pH values for the respective areas were between 7.21 and 7.76 for Papa Falls and between 7.46 and 9.21 for the Nxamasere Floodplains. These, however, excluding Nxamasere, fall well within the standards as set out in the 2nd edition of the South African Water Quality Guidelines for Domestic Use (DWAF 1996a), which states that the target water quality range for pH is 6 – 9.

The elevated pH value (dark orange) (Fig. 4.1) at the Nxamasere Floodplains could be due to salt deposits or evaporites in that area. This can further be verified by the total dissolved solids of the region. As mentioned in chapter 2, a fossil river which used to flow into the Delta from the west is situated at Nxamasere. When flood levels are high in the Delta water pushes up into this old river and as the floods recede, pools of various sizes are left behind. The water in these pools evaporates away with time and as this takes place dissolved salts and other substances become increasingly concentrated.

No significant effects on health, due to toxicity of dissolved metal ions and protonated species, are expected within pH 6 – 9. Furthermore, the taste should not be affected and metal ions (except manganese) are unlikely to dissolve readily in the water, provided that complexing ions or agents are present. In certain instances, slight metal solubility may occur at the extremes of this range, such as aluminium starts becoming more soluble at pH 6. Amphoteric oxides, on the other hand, may begin to dissolve at a pH of greater than 8.5 (DWAF 1996a).

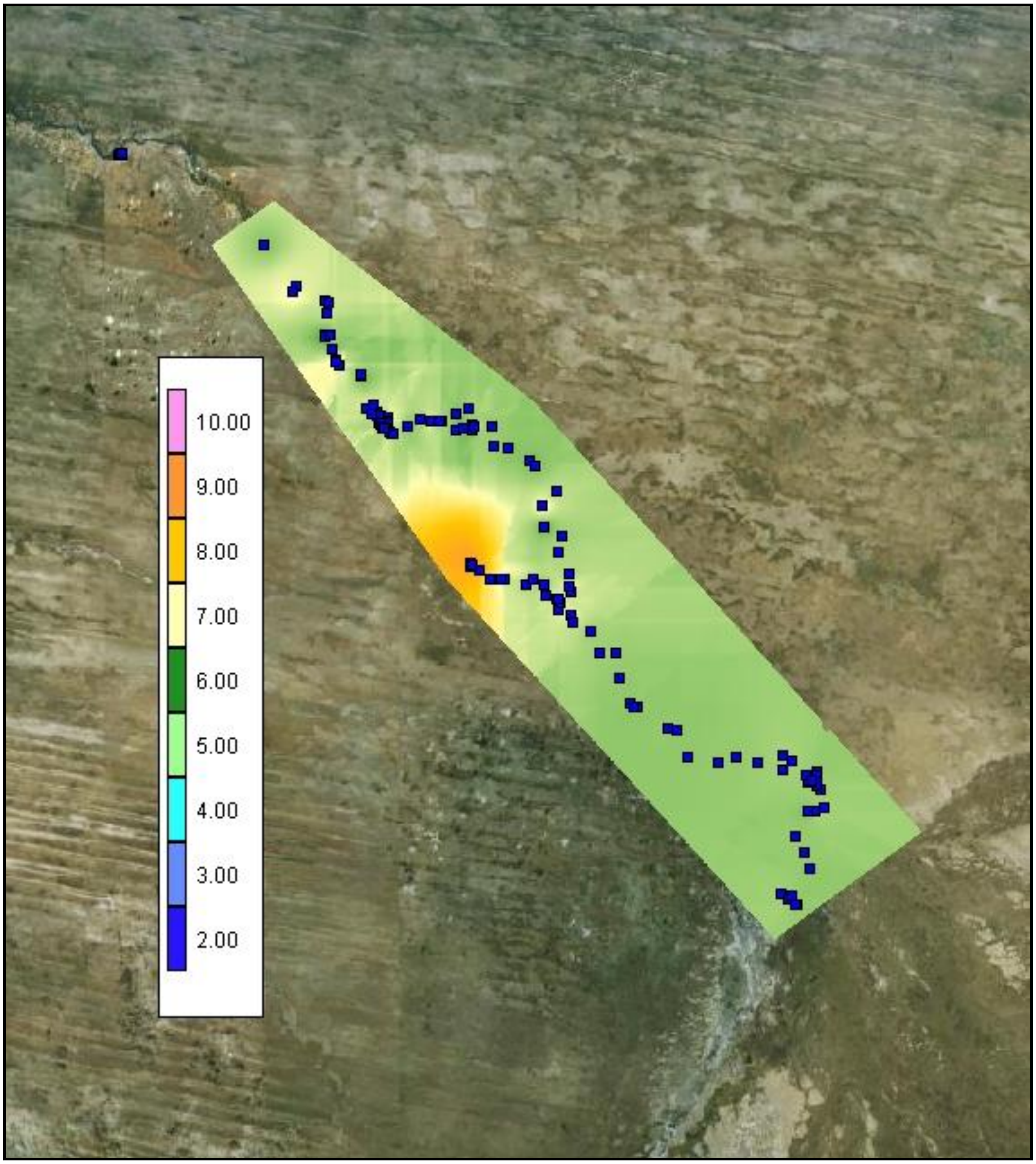


Figure 4.1: An extrapolated contour map illustrating the **pH** values obtained in the Okavango Delta Panhandle during all four trips, from December 2006 to January 2009. The green areas represent a pH range of 6.09 – 7.38 (ca. 5), while the dark orange area, at the Nxamasere Floodplains, indicates a maximum pH of 9.21 (ca. 8), which is probably due to salt deposits or evaporites in the region.

Also, the tolerance range for most freshwater fish falls between pH 6 – 9. There was no noteworthy difference in pH between the different seasons, nor was there from year to year. It can be concluded that the pH of the Okavango Delta Panhandle's water falls within the ideal water quality range and even the water at Nxamasere can be considered acceptable as the guidelines state that allowable consumable values should not exceed 5 – 9.5.

ELECTRICAL CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS

The electrical conductivity in most areas of the river, channels, lagoons and floodplains of the Okavango Panhandle, for all four trips, fell within the range of 2.70 to 5.90 mS/m (Fig. 4.2). At certain locations such as OR77 (Shakawe Floodplains), OR78 (in the Ngarange Channel), OR91 (in the Ngarange Channel), OR98 (in the Nxamasere Channel, close to Nxamasere Lodge), OR129 (mainstream close to Sepopa Swamp Stop) and Nxamalodge (Nxamasere Lodge) (Figs. 3.2 & 3.3) the electrical conductivity was slightly higher, being 10.78, 6.51, 6.34, 7.61, 7.34 and 7.10 mS/m, respectively. The Nxamasere Floodplains had a higher electrical conductivity ranging from 10.88 to 28.3 mS/m increasing as one moves further from the river. Once again, this is probably as a result of rapid evaporation in the pools, increasing the salt concentration.

As mentioned previously, conductivity refers to the number of ions in water and is a measurement of the ease with which water conducts electrical current. The conductivity of the Okavango Panhandle is very low and, therefore, it conducts electricity poorly and contains very few dissolved salts. This can be seen by the total dissolved solids of the area as well, which was in the range of 19 to 50 mg/L throughout the Panhandle and 102 to 198 mg/L in the Nxamasere Floodplains (Fig. 4.3).

The ionic content of natural water depends on the physical and chemical properties of the geological formations through which it flows and the low TDS and conductivity of the Panhandle can be as a result of the alluvium sands through which the water flows. These sands effectively filter out most of the conducting solutes. Water flowing through sand generally has an electrical conductance of less than 30 mS/m which is the case in the Okavango Panhandle. Furthermore, the ionic content of the water is affected by rainwater, which does not contain many solute constituents.

The catchment of the Okavango River is situated primarily on Kalahari Sand that represents the distribution of an ancient desert and is, therefore, sandy with little exposed rock. This has two very important consequences for the Okavango system as a whole. Firstly, water entering the Okavango Delta has an extremely low concentration of solutes due to the lack of weathering of rock taking place in the catchment and is, therefore, of high quality, chemically, with extremely low concentrations of plant macronutrients, such as nitrogen and phosphorus. The fraction of the catchment that is not on Kalahari Sand comprises granite. Therefore, the most important solutes entering the system are silica (by far the highest concentration), calcium, magnesium and sodium that enter the system as carbonate salts. Secondly, there is very little suspended clay and silt being brought into the system. The small quantity of suspended sediment entering the system is kaolinite with the bulk of the incoming sediment being fine-grained sand that is transported as bedload (Alonso and Nordin 2003).

Climatic conditions such as evaporation also determine the salt content at a specific point along the water course and it is due to evapoconcentration that the electrical conductivity and TDS in the Nxamasere Floodplains is higher than in the river, channels and lagoons.

It was mentioned previously that the rate at which TDS concentrations change and the duration of the change, seems to be more significant than the change itself and organisms which are adapted to wetlands with a low-salinity are generally sensitive to TDS concentration changes (DWAF 1996d). The target

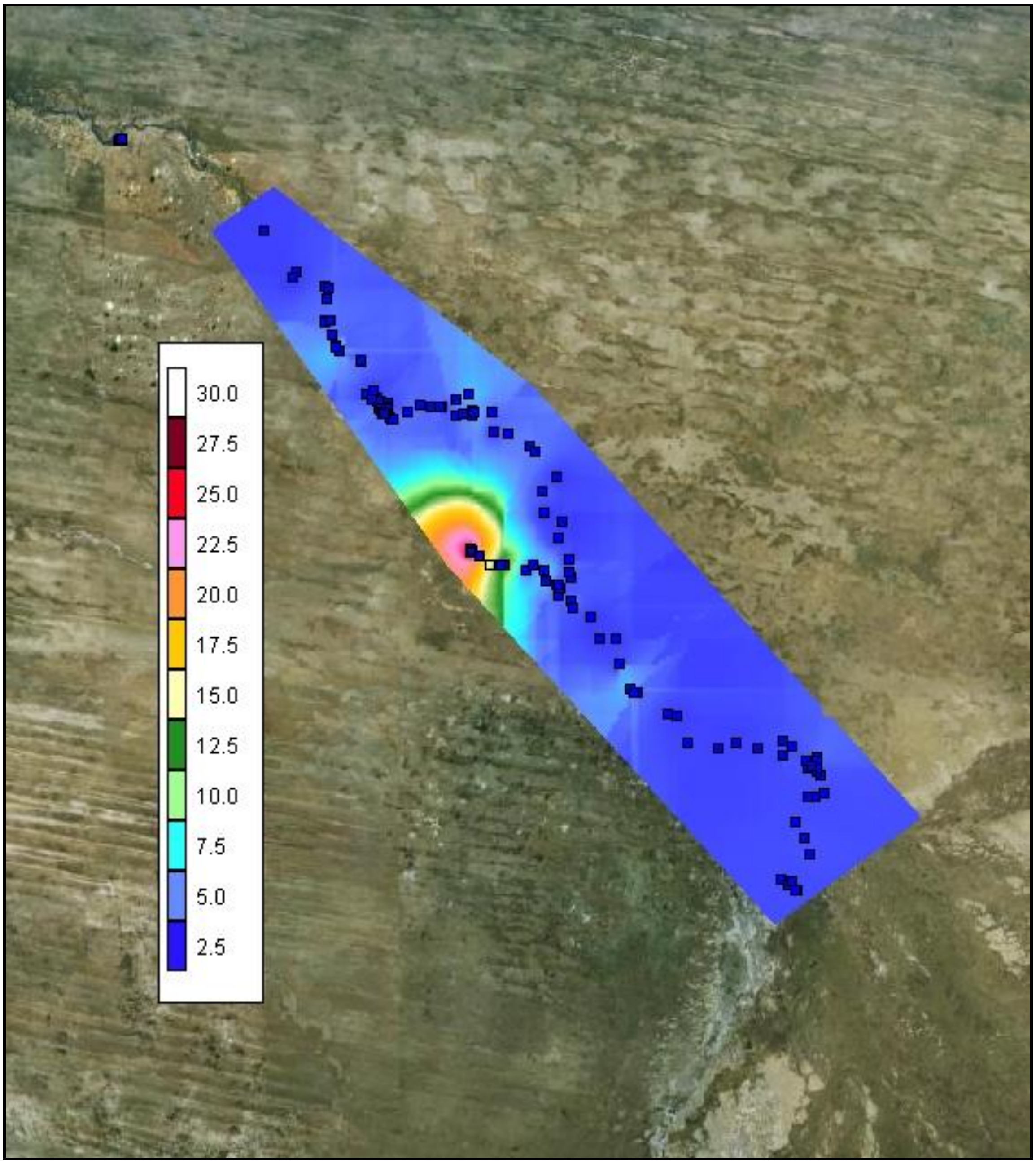


Figure 4.2: An extrapolated contour map illustrating the **electrical conductivity** (mS/m) values obtained in the Okavango Delta Panhandle during all four trips, from December 2006 to January 2009. The dark and light blue areas represent an electrical conductivity range of 2.70 to 5.90 mS/m, while the turquoise areas, visible at a few locations along the Panhandle, indicate areas with an electrical conductivity between 6.34 and 7.61 mS/m, with the exception of OR77, which was 10.78 mS/m in November 2007. The colours ranging from light green to maroon indicate values between 10.88 and 28.3 mS/m in the Nxamasere Floodplains.

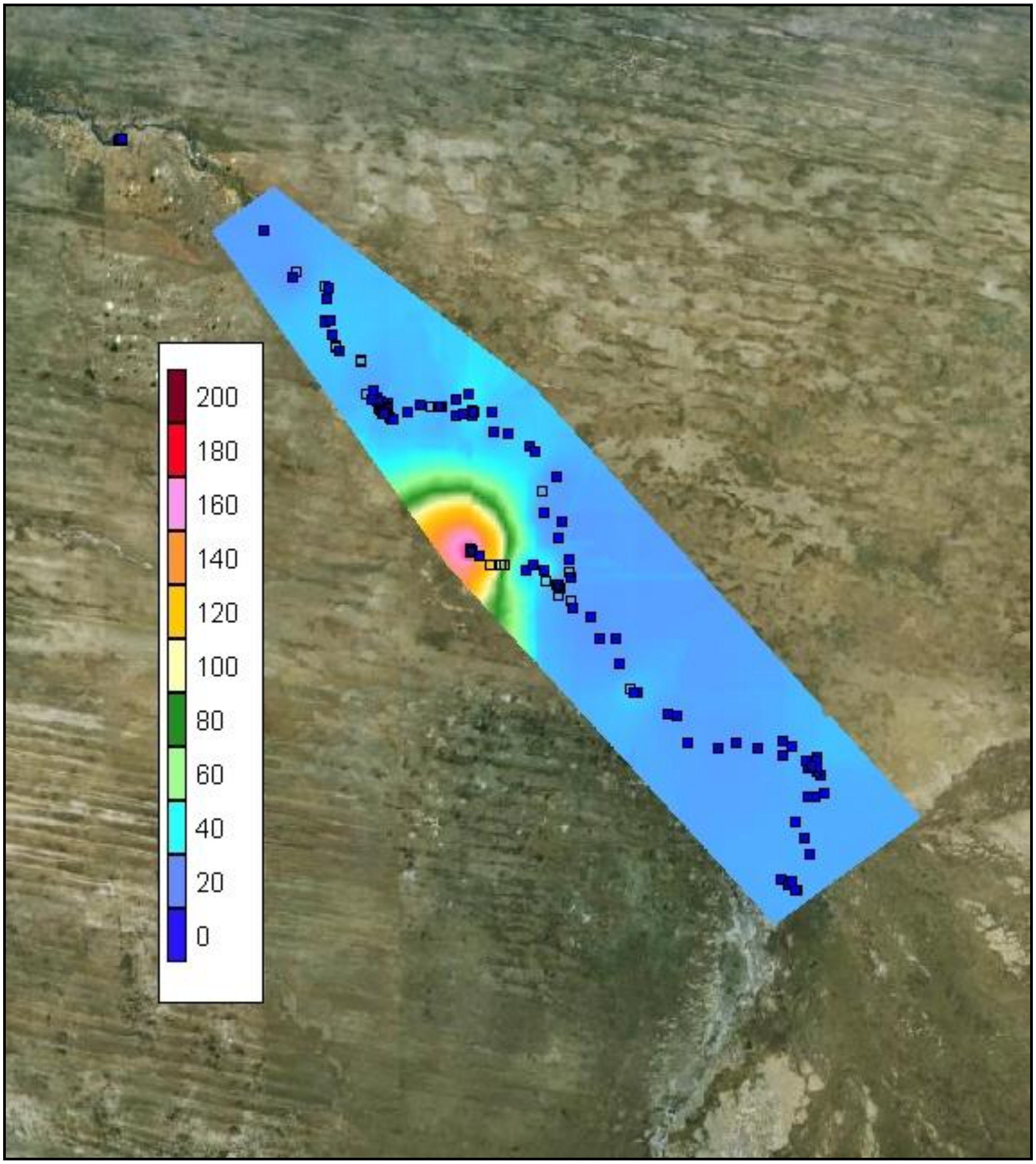


Figure 4.3: An extrapolated contour map illustrating the **total dissolved solids** (mg/L) values obtained in the Okavango Delta Panhandle during July 2008 and December/January 2008/2009. The light blue and turquoise areas represent a total dissolved solids range of 19 to 50 mg/L, while the multicoloured area represents total dissolved solids concentrations between 102 and 198 mg/L in the Nxamasere Floodplains.

water quality range for all inland aquatic ecosystems is stated in terms of case- and site-specific TDS concentrations which should not be changed by >15 % from the normal cycles of the water body under un-impacted circumstances (DWAF 1996d). From December 2006 to January 2009 the TDS concentrations or electrical conductivity values remained constantly low and, therefore, it should not have impacted this aquatic ecosystem.

The target water quality range for domestic use is less than 70 mS/m for electrical conductivity and 0 to 450 mg/L for total dissolved solids. The water of the Okavango Panhandle, including the Nxamasere Floodplains, therefore, lies well below the range of less than 70 mS/m. The taste threshold for dissolved salts in water is in the region of 45 mS/m (300 mg/L TDS), which means that not even the water in the Nxamasere Floodplains will have a salty taste. Furthermore, below the above-mentioned values, no health effects are expected.

TURBIDITY

In order to determine the turbidity or the light-scattering ability of the water, secchi disk readings were taken at all the sites.

During trip 3 (July 2008) when water levels were highest, following the arrival of the annual flood, the water in the Panhandle was extremely clear. The secchi disk's pole/handle was lengthened by attaching it to a steel pole of 3.5 m in length, increase the distance that it could be lowered into the water up to 4 m. In places where the water was less than 4 m deep the secchi disk could be seen till the bottom. Where the water was even deeper than four meters, the secchi disk was visible for the full 4 m and beyond, such that, at some extremely deep areas, the plants and fish could still be seen at the bottom. This indicates extremely low volumes of suspended solids, such as sand particles and inorganic and organic material, which usually is both detritus and living organisms. Therefore, due to this low turbidity, the potential for transmission of infectious diseases is minimal. Turbidity is usually attributed to eutrophication. The water in the Okavango Delta is not eutrophic, excluding Lake Ngami and some isolated pools in the Nxamasere Floodplains. This is because the Delta has extremely low nutrients levels, which are not sufficient for algal blooms.

During trips 1 (December 2006), 2 (October and November 2007) and 4 (December 2008 and January 2009), however, the distance to which the secchi disk was visible was much less. During these three trips the water levels were notably lower than in July 2008, as the floods from Angola had already passed through the Panhandle and the local rains had either not come yet or had only started shortly before sampling had begun.

During trip 1, the lowest secchi reading was 1.25 m, which was obtained at a number of sites. The highest reading was 2 m, obtained at OR93, which is situated more or less in the centre of Samochima Lagoon.

Of the samples taken during trip 2, in which the secchi disk was not visible to the bottom, the lowest reading was 0.75 m at OR98 and the highest reading was 1.95 m at OR88. At OR89, however, a reading of 2.09 m was obtained, at which depth the secchi disk reached the bottom. OR98 is situated in the Nxamasere Channel, before one reaches Nxamasere Lodge from the mainstream and OR88 is situated in Samochima Lagoon, close to where the boats are launched. OR89 is also situated in Samochima Lagoon, but more towards the centre close to OR93.

During trip 4, the secchi disk was never visible till the bottom. The lowest reading during this trip was 0.75 m at OR52, while the highest reading was 1.95 m at both OR64 and OR67. OR52 is situated in the entrance to the Ngarange Channel, OR64 is in Little Dead Croc Lagoon upstream from Samochima Lagoon and OR67 was taken in a tiny narrow inlet between papyrus just downstream of Samochima's fisheries (Figs. 3.2 & 3.3).

The low secchi disk readings obtained during trips 1, 2 and 4 indicate a high turbidity and, consequently, relatively high volumes of suspended solids. In the Okavango Panhandle, such turbid waters are mainly as a result of suspended sand particles.

WATER TEMPERATURE

During December 2006 (trip 1), water temperatures were between 25 and 34.5 °C with a mean average water temperature of 27.15 °C (Fig. 4.4). The water temperatures above 30 °C were all obtained in shallow water. During October and November 2007 (trip 2), the mean average water temperature was close to that of trip 1, being 27.32 °C. The maximum and minimum water temperatures during this trip were 32 and 25 °C, respectively. The water temperature range was small in December 2008 and January 2009 (trip 4) with a high of 31.29 °C and a low of 28.06 °C. The mean average during this trip was 29.23 °C, which is higher than the average temperatures for trips 1 and 2. As expected, the winter month of July 2008 (trip 3) had lower water temperatures than did the other three trips undertaken during the summer months. This month showed a maximum water temperature of 27.27 °C and a minimum of 14.91 °C, the mean average being 17.13 °C. All samples were taken during daylight, between 09:40 and 19:09.

The tremendous difference in maximum and minimum temperatures can be due to a number of factors such as:

- time of day;
- density of vegetation cover;
- depth and volume of water;
- turbidity; and
- channel structures.

These conditions varied throughout the sampled area as sampling sites were scattered throughout the river, lagoons and floodplains. Other factors, which are not only responsible for the differences in temperature over space, but also over time, such as the difference between December 2006 and December 2008 and between the winter month of July and the summer months include:

- flow rate and the rate of discharge;
- air pressure;
- air temperature;
- wind speed;
- cloud cover; and
- rainfall events.

An example of this is that not only was the average water temperature higher in December 2008 than in December 2006, but also the average atmospheric temperature (Fig. 4.5). There was a mean water temperature difference of more than 2 °C between the two years and a mean atmospheric temperature difference of more than 4.5 °C. The mean atmospheric temperature obtained during October and November 2007 also indicates a rise, being just short of 4 °C higher than the average obtained in December 2006 and about 1 °C lower than that of December 2008. However, daily and yearly periodicity patterns are characteristic of surface waters as climatic conditions do not always remain exactly the same from year to year or from day to day.

DWAF (1996d) states that water temperatures in aquatic ecosystems should not change by more than 2 °C or more than 10 % of the normal temperature for that specific ecosystem at a certain time of day. Because all organisms have different temperature tolerance ranges, if small changes in temperature remain so for a period of time, it might alter the community composition of a water body. Therefore, if the increase in water temperature, from December 2006 to December 2008 remains high, it will cause a shift in the community composition of the Okavango Panhandle. High, quick changes in temperature may be lethal to aquatic organisms.

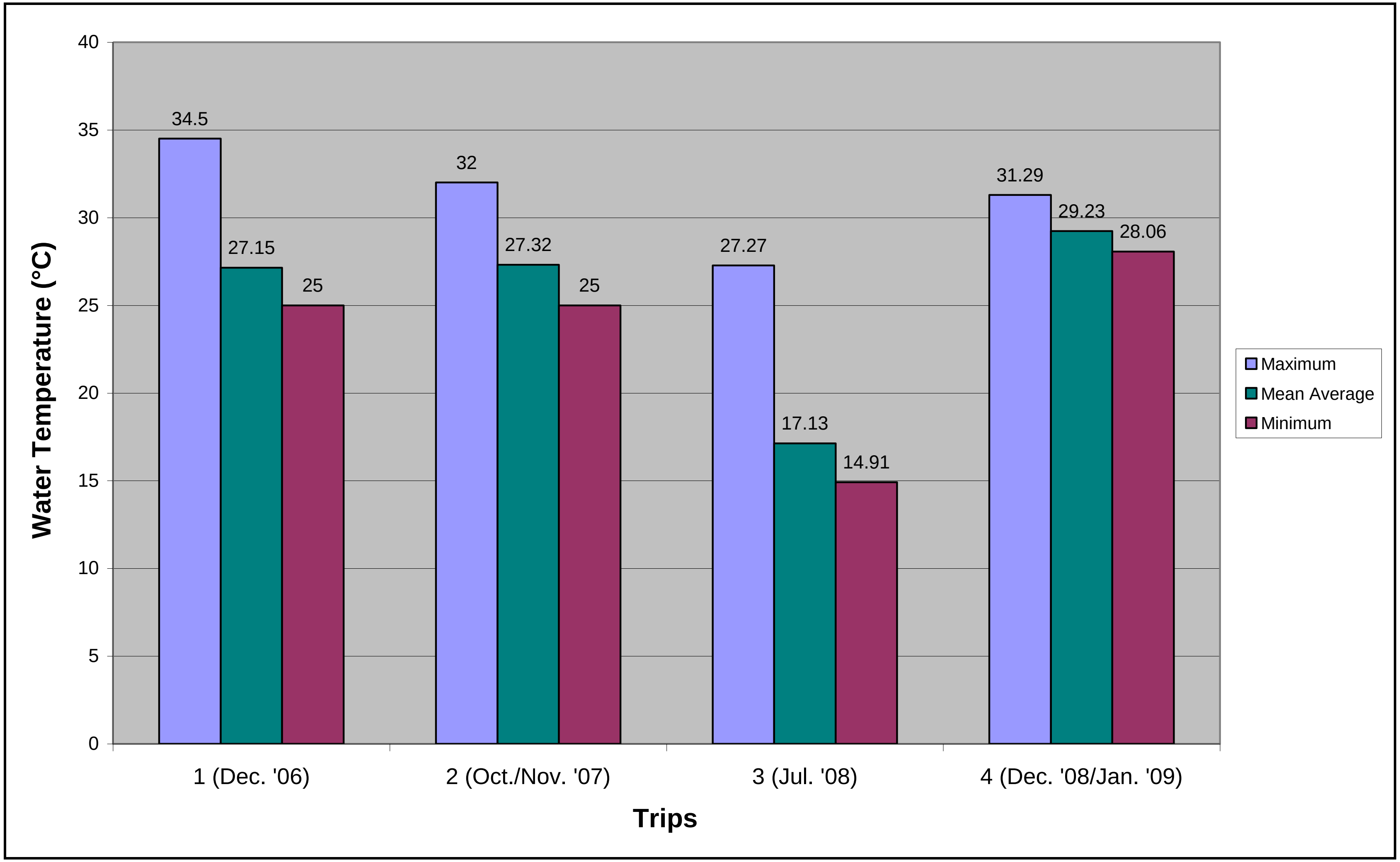


Figure 4.4: The maximum, mean average and minimum **water temperatures** (°C) recorded in the Okavango Delta Panhandle during December 2006, October and November 2007, July 2008 and December and January 2008/2009.

DISSOLVED OXYGEN

DWAF (1996d) states that dissolved oxygen levels should be between 80 and 120 % saturation in aquatic ecosystems, as aquatic organisms need sufficient oxygen to survive. In the Okavango, however, dissolved oxygen levels are mostly extremely low, ranging from 2.6 to 179 % saturation (Fig. 4.6 & Fig. 4.7). In December 2006, DO saturation ranged between 2.6 and 71.4 %, with a mean average of 24.2 %. Even lower saturations were obtained in December 2008 and January 2009. During this trip (trip 4), the maximum obtained was 27.4 %, the minimum was 3 % and the mean average was 11.7 %. DO saturation decreases when water temperature increases and increases when the temperature decreases. Therefore, the lower oxygen levels in December 2008 than in December 2006 could be because of the higher mean average air and water temperatures in 2008.

This can also be seen when one looks at the DO saturations obtained in the winter month of July 2008. During this month when the air and water temperatures were lowest, a mean average DO saturation of 71.4 % was obtained with a maximum of 179.5 % and a minimum of 18.4 %. Although many of the values in the Panhandle itself were higher than for the other trips, the highest values obtained during this time (July 2008) were obtained at Popa Falls and the Nxamasere Floodplains (Figs. 3.2 & 3.3). At Popa Falls the water crosses a series of rapids and flow rates here are faster than in the Panhandle. Water at Popa Falls is, therefore, well aerated. In the Nxamasere Floodplains, however, high oxygen conditions are due to the eutrophic conditions in the isolated pools. Algae in these pools produce a lot of oxygen and unlike the Delta, where most aquatic plants release their oxygen above the water, plants in the Nxamasere pools release oxygen into the water. Furthermore, these pools are shallow, with large surface areas over which gaseous exchange can take place.
In October and November 2007 a mean average of 45.1 % was obtained, with a minimum of 4.6 % and a maximum of 140.1 %. This maximum value was also obtained in the Nxamasere Floodplains.

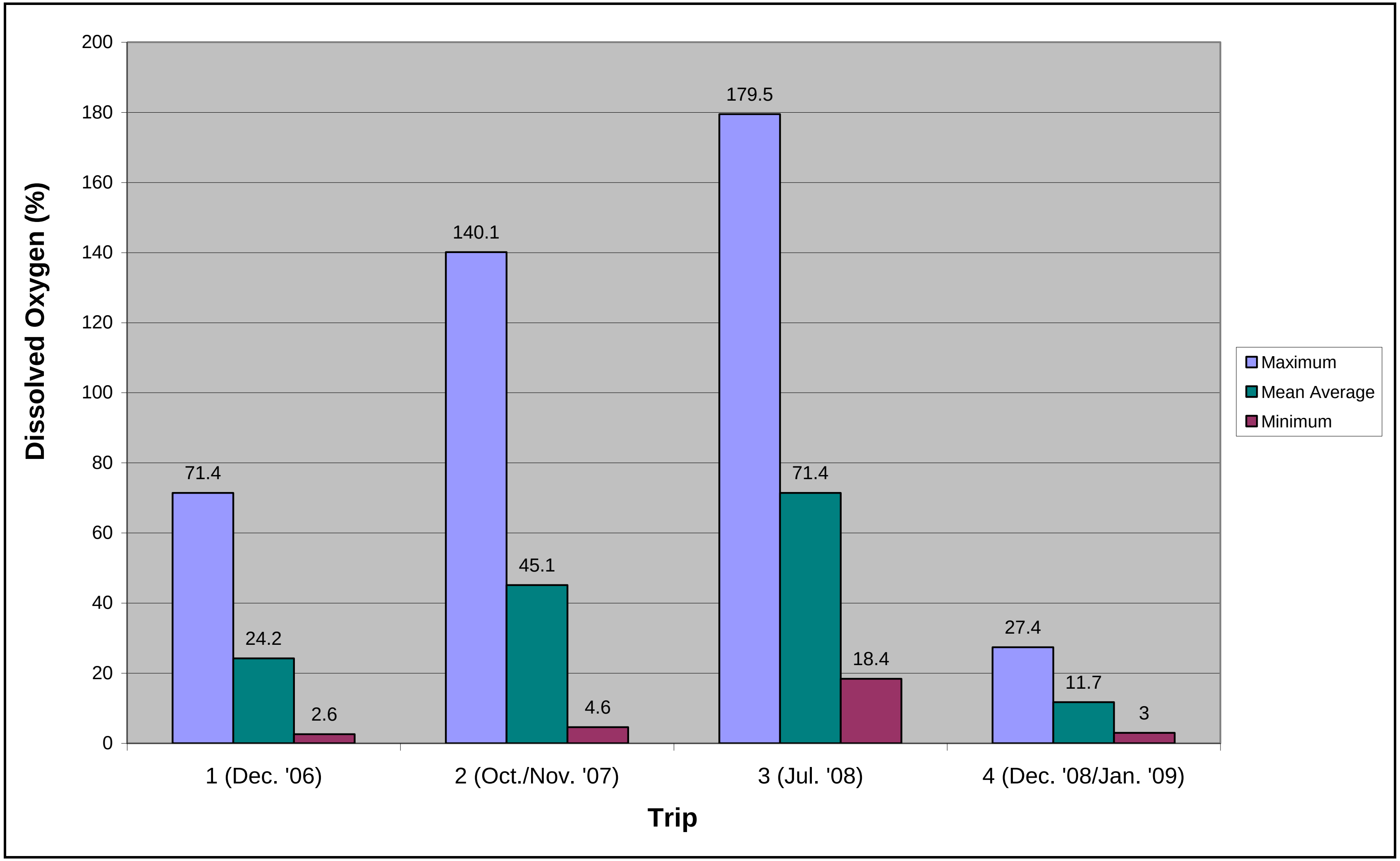


Figure 4.6: The maximum, mean average and minimum **dissolved oxygen (DO) saturation** obtained in the Okavango Delta Panhandle during December 2006, October and November 2007, July 2008 and December and January 2008/2009.

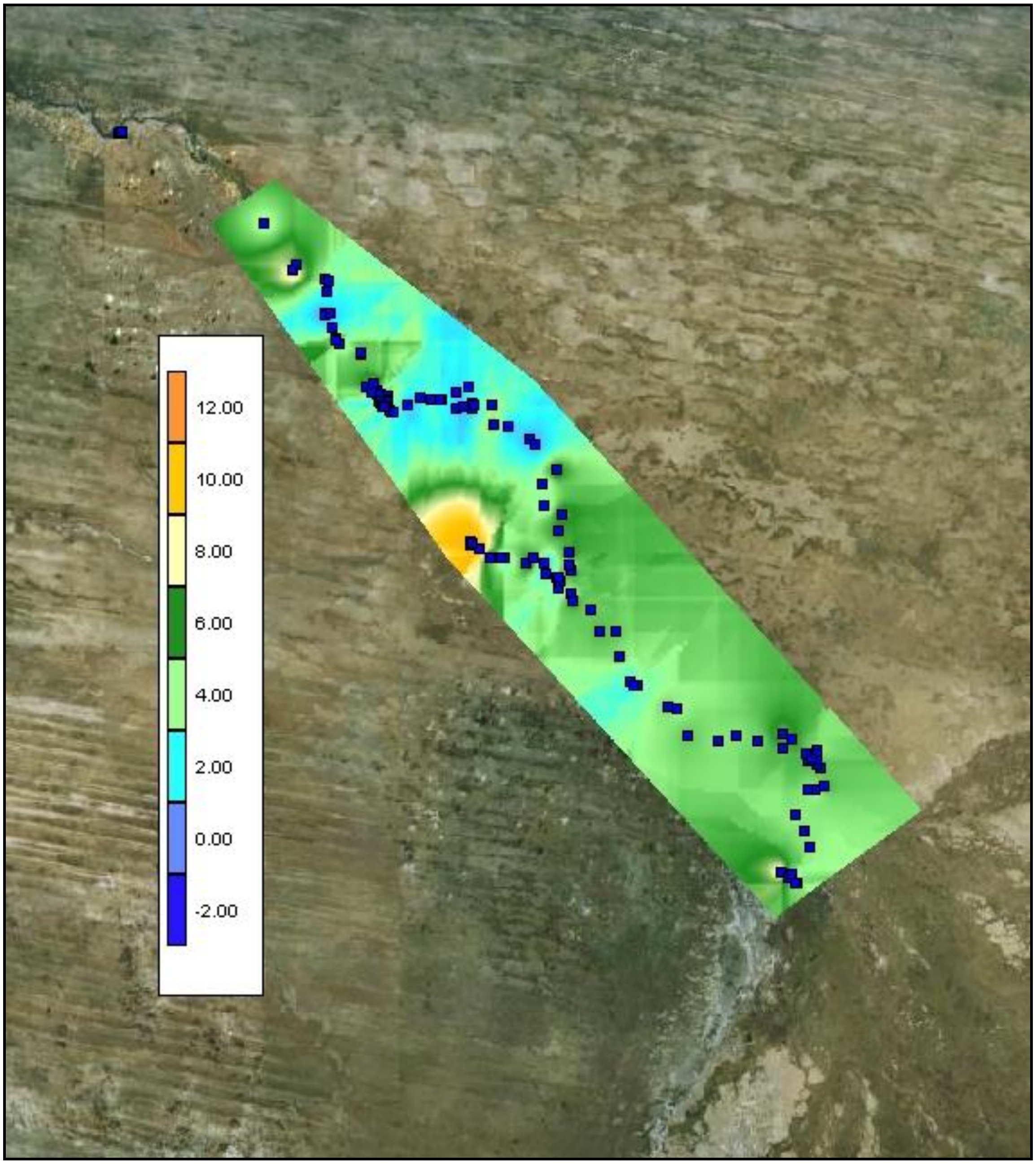


Figure 4.7: An extrapolated contour map illustrating the **dissolved oxygen (DO)** (ppm) values obtained in the Okavango Delta Panhandle during all four trips. The blue, turquoise and green areas represent DO values of between 0.2 and 6 ppm, while the cream and orange area represents DO concentrations between 6.02 and 12.74 ppm in the Nxamasere Floodplains.

The generally low DO saturations in the Okavango are mainly due to the fact that the water flows over an extremely flat terrain and flow rates are low. The speed at which the water travels is further reduced by the vegetation of the floodplains. The lowest levels of oxygen were obtained in the Ngarange Channel (Fig. 3.2) and the Kalatog. This is mainly due to the fact that most water in these side channels comes from below papyrus beds, where conditions are almost anoxic.

FLUORIDE (F)

Most fluoride values obtained were below 0.1 mg/L, with the exception of three sites (Fig. 4.8). The lowest of the fluoride values was 0.01 mg/L which was recorded at OR61 in July 2008. At OR77 a value of 0.13 mg/L was recorded in November 2007, while in October 2007 values of 0.14 and 0.24 mg/L were recorded at OR131 and OR132. OR131 and OR132 are both situated in the Nxamasere Floodplains, while OR61 and OR77 are situated in close proximity to each other in the region of Shakawe (Figs. 3.2 & 3.3). This indicates that the fluoride concentration of the water at Shakawe decreased from November 2007 to July 2008. The most likely cause for this drop in fluoride concentration can be the arrival of the annual flood, which is at its highest in July and flushes the system. The increase in the volume of water can also decrease the concentration of dissolved substances.

The concentration of fluoride in unpolluted surface water is typically 0.1 – 0.3 mg/L, which means that the concentrations found at OR77, OR131 and OR132 are normal. It is rather the lower than 0.1 concentrations, obtained at the rest of the sites sampled, that are unusual. Only when fluoride concentrations exceed 3 – 6 mg/L do they pose a threat. A small amount of fluoride, however, is needed during tooth formation to harden dental enamel and to increase resistance to attack on tooth enamel by bacterial acids and water is estimated to contribute between 50% and 75% of the total dietary fluoride intake in adults. The fluoride concentrations in the Okavango Delta Panhandle may, therefore, be less than required. However, as mentioned previously, the optimum concentration of

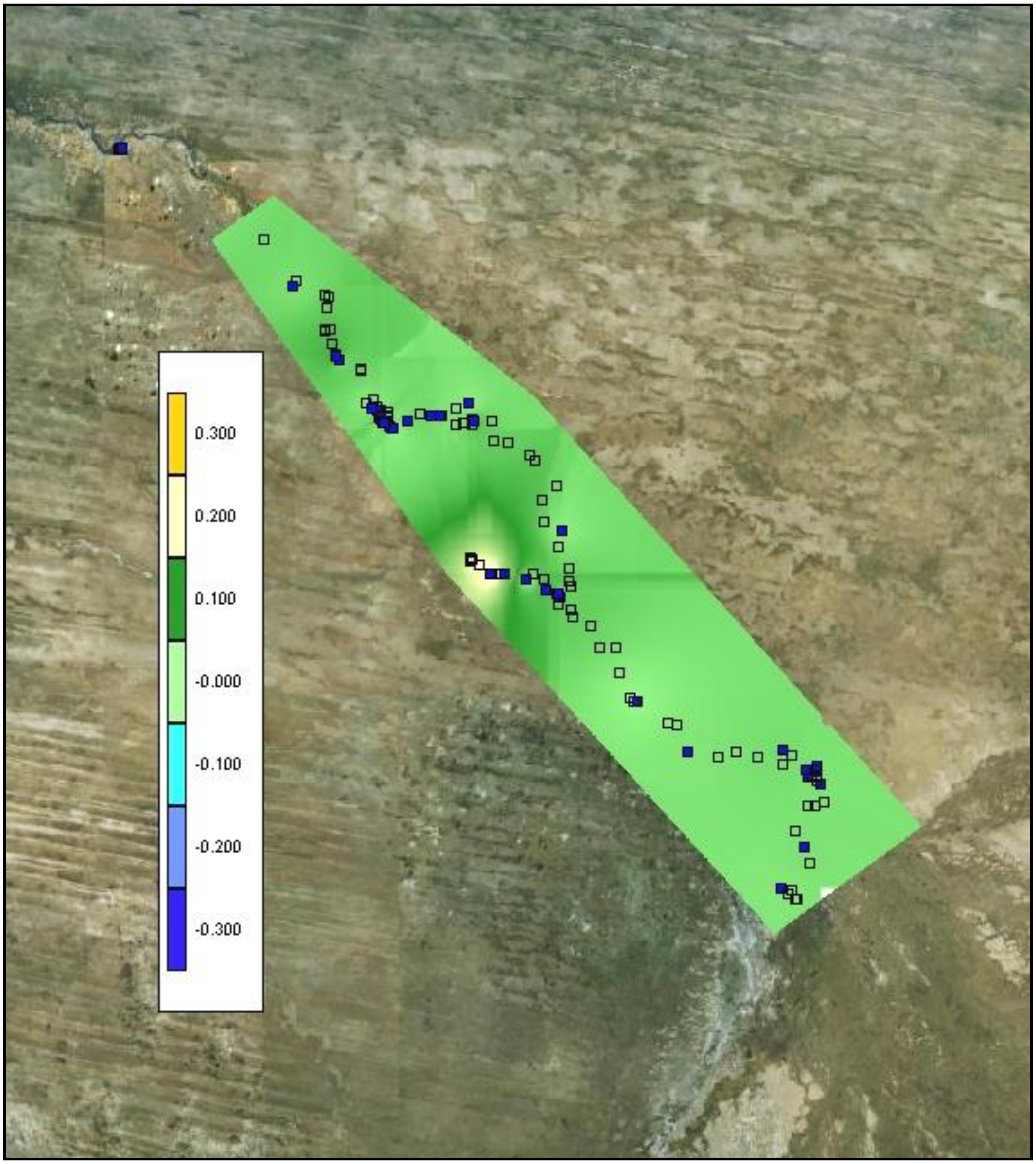


Figure 4.8: An extrapolated contour map illustrating the **fluoride** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The light green areas represent values of less than 0.1 mg/L, while the dark green and cream colours represent values greater than 0.1 mg/L at the Nxamasere Floodplains.

fluoride in water is a function of water intake as air temperature has a strong influence on water consumption – the hotter it is, the more water is consumed. Due to the fact that temperatures can be extremely high in the area, people may consume more water, making the low fluoride concentrations ideal.

CALCIUM (Ca)

The calcium concentration throughout the Okavango Panhandle during the first three trips ranged between 1.28 and 5.06 mg/L, with the exception of two sampled sites (OR131 and OR132) taken in the Nxamasere Floodplains in October 2007 (Fig. 4.9). These concentrations were 6.77 and 22.76 mg/L, respectively. Of the samples taken in the Panhandle only one (OR98), which was sampled in October 2007, was above 5 mg/L, the second highest concentration being 4.74 mg/L. OR98 lies in the Nxamasere Channel close to Nxamasere Lodge (Figs. 3.2 & 3.3).

Concerning calcium, the Okavango Panhandle’s water can be compared to rain water, as rain water or soft waters usually have a calcium content of less than 10 mg/L. The target water quality range for calcium is 0 to 32 mg/L. At this concentration people should show no health effects and the water will not cause scaling. Even the extreme value of 22.76 mg/L, obtained at the Nxamasere Floodplains, falls well within this range.

It must, however, be kept in mind that people require calcium daily, the daily intake required being between 500 and 1400 mg/day (domestic use). Let us use extremes to make calculations and say that the local people each drink three litres of water per day from OR98. Three multiplied by 5.06 equals 15.18 mg of calcium per day and even if they drank from OR132 in the Nxamasere Floodplains they would only take in 68.28 mg/day. With such low calcium concentrations in the water people in the area should make sure they eat enough calcium-rich foods.

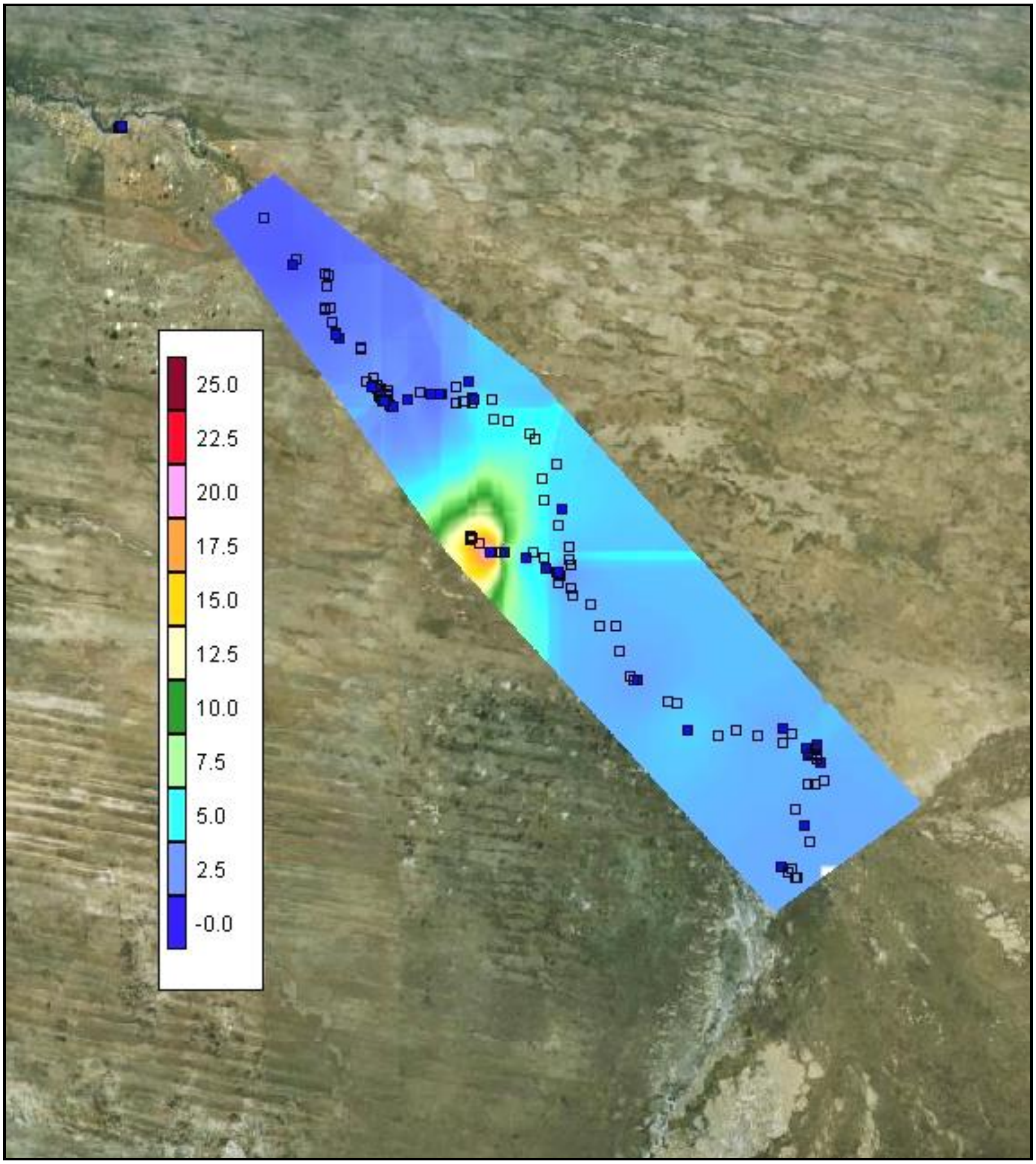


Figure 4.9: An extrapolated contour map illustrating the **calcium** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The dark blue, light blue and turquoise areas represent values from 1.28 to 5.06 mg/L, while the multicoloured area represents two values of 6.77 and 22.76 mg/L, obtained at the Nxamasere Floodplains in October 2007.

Calcium is not mentioned in the South African Water Quality Guidelines for Aquaculture and neither in the guidelines for aquatic ecosystems. The target water quality range for livestock watering is 0 to 1000 mg/L for all species.

MAGNESIUM (Mg)

Magnesium concentrations throughout the Panhandle, during the first three trips, were extremely low (Fig. 4.10), with a minimum of 0.28 mg/L and a maximum of 1.03 mg/L, obtained at OR36 in the vicinity of Seronga. At OR131 and OR132, in the Nxamasere Floodplains (Figs. 3.2 & 3.3), magnesium concentrations were 1.50 and 4.11 mg/L, respectively.

The concentration of magnesium in freshwater is typically between 4 and 10 mg/L, but the water of the Okavango Panhandle is even lower. The target water quality range for Magnesium is 0 to 30 mg/L, at which concentrations water should not have a bitter taste and should not cause health effects or scaling. Compared to the above-mentioned figures, the water of the Panhandle seems to contain almost no magnesium. As is the case with calcium, humans need a certain amount (more or less 250 mg) of magnesium daily to remain healthy. With such low concentrations in the water, people will have to obtain their daily magnesium intake from elsewhere.

The target water quality range for livestock watering is from 0 to 500 mg/L (DWAF 1996b), while there are no guidelines concerning magnesium for aquatic ecosystems or for aquaculture.

SODIUM (Na)

Sodium concentrations in the Panhandle were as low as 2.69 mg/L and not higher than 9.73 mg/L (Fig. 4.11). This maximum value was obtained at Mohembo (OR55) in July 2008. The values obtained at Popa Falls in the Caprivi Strip (Figs. 3.2 & 3.3) were higher than most of the concentrations obtained in the Panhandle, being between 8.38 and 9.45 mg/L. At OR132, in the Nxamasere

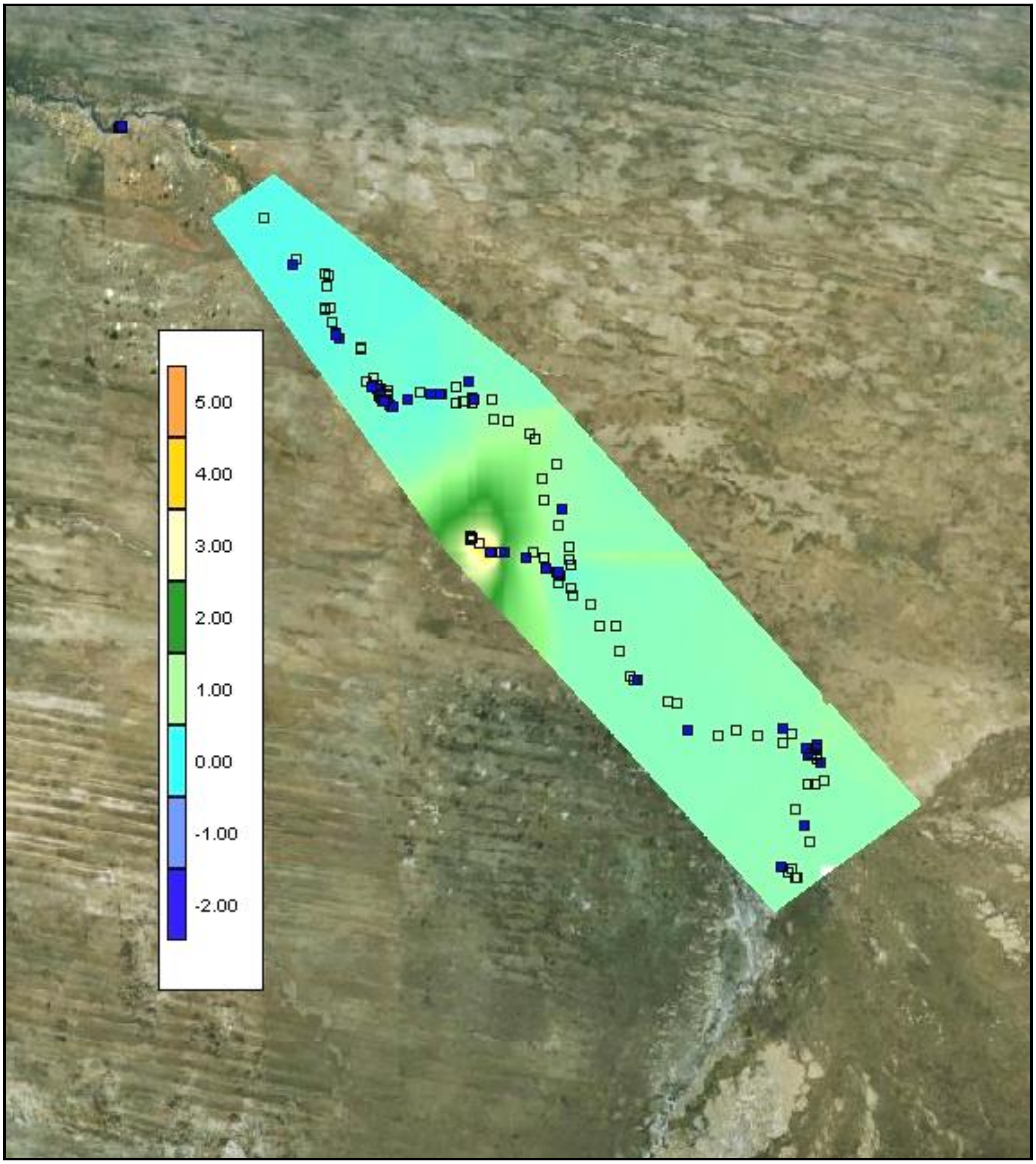


Figure 4.10: An extrapolated contour map illustrating the **magnesium** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The turquoise and light green areas represent values from 0.27 to 1.03 mg/L, while the dark green and orange areas represent two values of 1.50 and 4.11 mg/L, respectively, obtained at the Nxamasere Floodplains in October 2007.

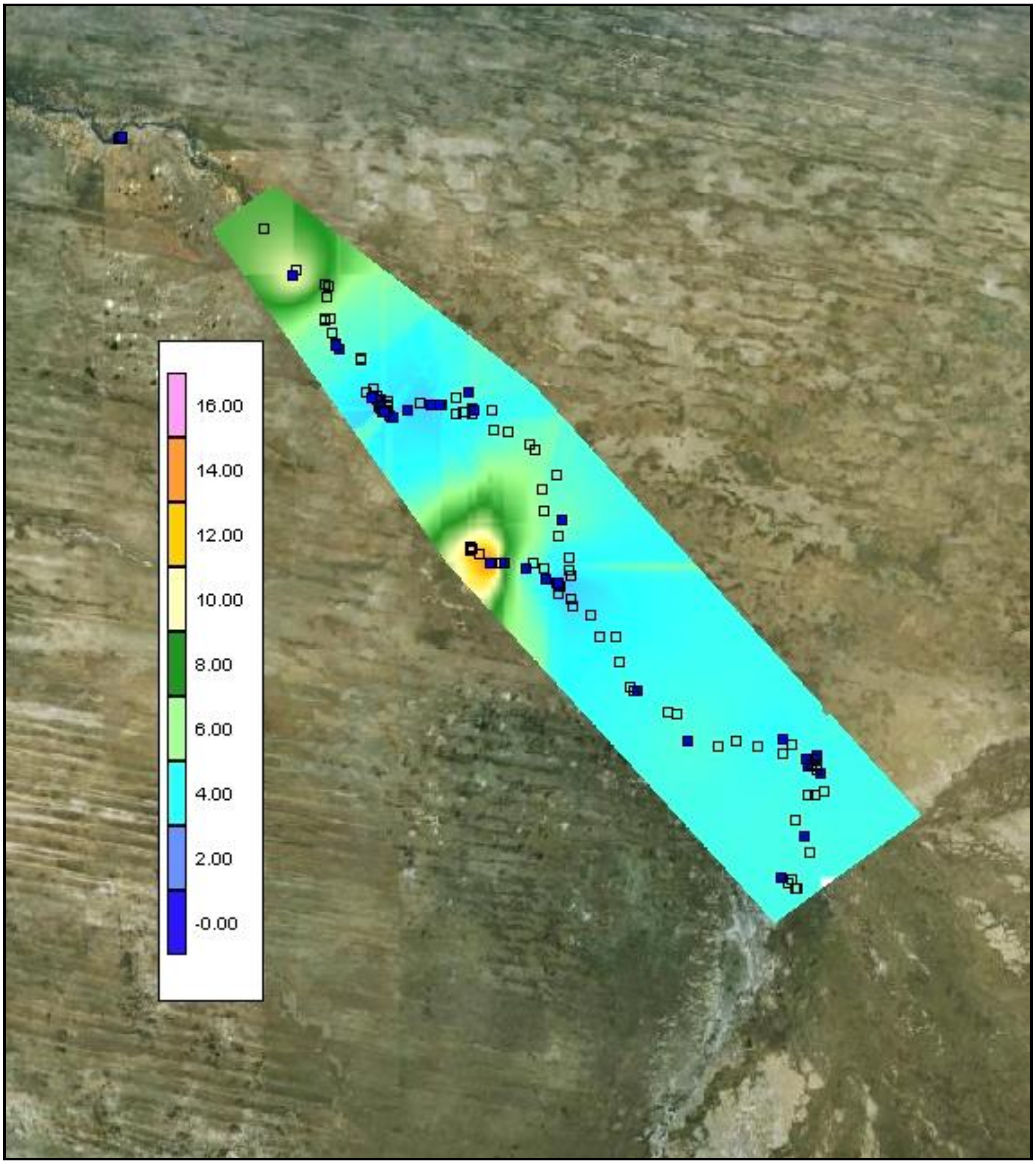


Figure 4.11: An extrapolated contour map illustrating the **sodium** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The turquoise, light green and dark green areas represent values from 2.69 to 8.29 mg/L, while the cream colour up north represents a value of 9.73 mg/L, obtained at Mohembo (OR55) in July 2008. The orange colour represents a value of 15.44 mg/L, obtained at the Nxamasere Floodplains in October 2007.

Floodplains, the sodium concentration was found to be 15.44 mg/L in October 2007.

As mentioned previously, concentrations of sodium vary tremendously in water, both over time and space. It is usually low in fresh water (<50 mg/L) in regions where rainfall is high, but can reach levels as high as 500 mg/L in areas with little rainfall (WRC 1998). Despite the fact that rainfall is low in the vicinity of the Okavango Delta, the sodium concentration in this wetland is extremely low, even lower than in areas with high rainfalls (see ‘Changing Channels’, Chapter 2).

The target water quality range for domestic use is 0 to 100 mg/L and it is clear that the water of the Okavango Panhandle is not even close to exceeding this limit. The target water quality range for livestock watering is even bigger (0 to 2,000 mg/L), while nothing is mentioned of sodium in the guidelines for aquatic ecosystems and for aquaculture.

CHLORIDE (Cl)

The chloride concentrations in the river, lagoons, channels and swamps (including the Nxamasere Floodplains) were between 0.59 and 3.26 mg/L, the latter being in Samochima Lagoon. Two single sites showed elevated chloride levels (Fig. 4.12). At OR6 the chloride concentration was found to be 4.74 mg/L in July 2008. This site is situated between Red Cliffs and the Nxamasere Channel (Figs. 3.2 & 3.3), on a meander bend in a stretch of river that is largely clear of human activity. The exposed sandbank on this bend is a popular spot for African skimmers to nest. The highest chloride concentration (6.47 mg/L) was obtained in the floodplain at Shakawe village (OR77) in November 2007. The chloride concentrations at Popa Falls were slightly higher than the concentrations in the Panhandle. These concentrations ranged from 3.27 to 4.18 mg/L and were sampled in July 2008.

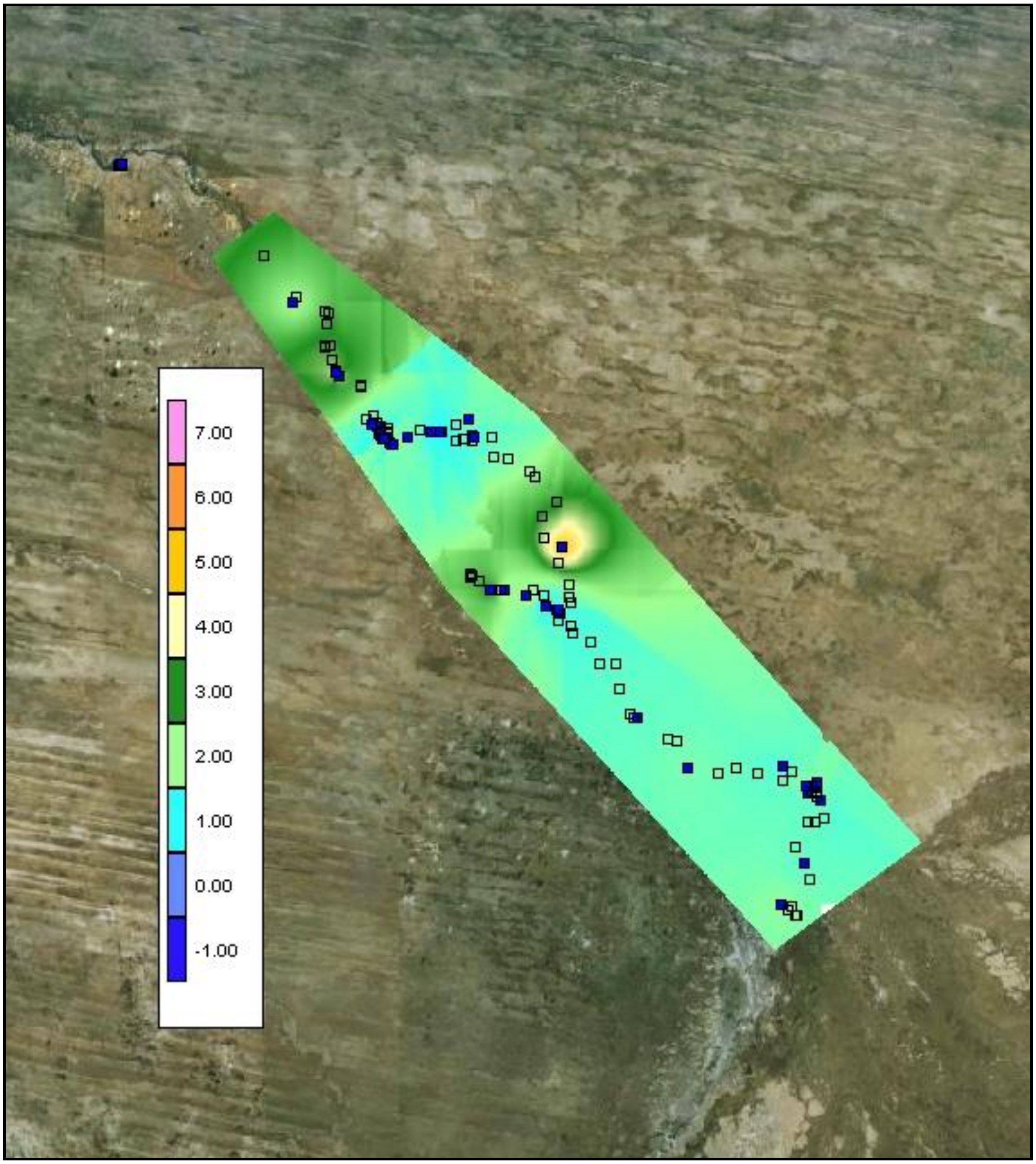


Figure 4.12: An extrapolated contour map illustrating the **chloride** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The turquoise, light green and dark green areas represent values from 0.59 to 3.26 mg/L, while the orange colour represents a value of 4.74 mg/L, obtained in the mainstream between Red Cliffs and the Nxamasere Channel (OR6) in July 2008.

Chloride concentrations are typically less than 10 mg/L in freshwater and the Okavango Panhandle's water has concentrations well below this, even the highest concentration at Shakawe. The target water quality range for domestic use is much higher though (0 to 100 mg/L) and at these levels chloride causes no aesthetic or health effects. The water of the Panhandle is, therefore, very safe for human consumption, concerning chloride.

For livestock watering the target range is between 0 and 1,500 mg/L and only chlorine (Cl_2) is discussed in the guidelines for aquatic ecosystems and for aquaculture, but it is not normally present in natural waters. This is because it is too reactive to persist in the aquatic environment and only occurs here as a result of, amongst others, chlorination of drinking water, sewage treatment and industries (DWAF 1996d).

POTASSIUM (K)

At all sites sampled within the Okavango Delta the concentrations ranged from 1.01 to 2.66 mg/L, with the exception of a single sample (OR77) taken at the Shakawe Floodplain and two samples (OR131 and OR132) from the Nxamasere Floodplains (Figs. 3.2, 3.3 & 4.13). The water in the floodplain at Shakawe was sampled in November 2007 and had a potassium concentration of 9.60 mg/L. However, this same site was sampled earlier in December 2006 as well and only had a concentration of 2.46 mg/L.

What could have caused the difference in potassium concentration over time is the fact that water levels were higher in December 2006 than in November 2007. In December 2006, the floodplain was covered by a layer of shallow water, connected to the mainstream, while in November 2007 the floodplain had a pool of water which was disconnected from the main stream. The water, therefore, was not constantly being replaced in November 2007 as it was in December 2006 and as it was evaporating from the disconnected pool, the potassium present was probably becoming more concentrated.

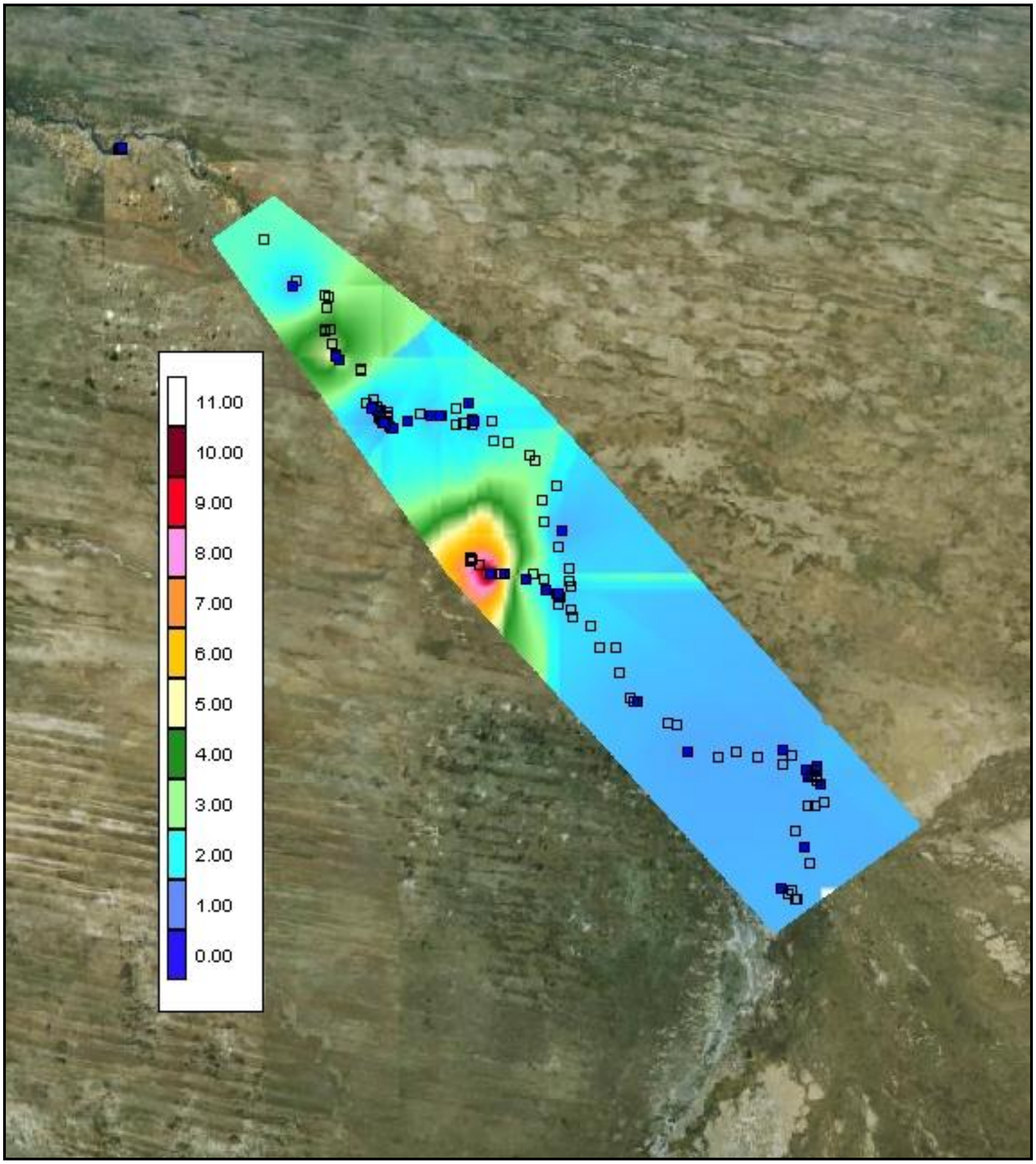


Figure 4.13: An extrapolated contour map illustrating the **potassium** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The light blue, turquoise and light green areas represent values from 1.01 to 2.66 mg/L, while the darker coloured area, at Shakawe (OR77), represents a value of 9.60 mg/L, sampled in November 2007. The multicoloured area represents two values of 4.65 and 10.82 mg/L, obtained at the Nxamasere Floodplains in October 2007.

This was probably also the case at the two sites (OR131 and OR132) in the Nxamasere Floodplains, where concentrations of potassium were 4.65 and 10.82, respectively. These pools are also disconnected from flowing water and are exposed to high evaporation rates.

Potassium is essential in the human diet and dietary intake ranges from 1.6 to 4.7 g/day (DWAF 1996a), that is 1,600 to 4,700 mg/day. If one drinks 3 L of OR132's water per day, one would only get 32.46 mg of potassium from one's water. This is extremely low and one would have to make sure that what you consume makes up for the rest. Concentrations of potassium are generally low in fresh, unpolluted water (2 to 5 mg/L) and this is reflected in the concentrations of potassium in the Panhandle, with the exception of that at OR77 and OR132.

The target water quality range for potassium is 0 to 50 mg/L. Therefore, even though the concentrations at OR77 and OR132 are higher than for typical freshwater, they still fall within the ideal water class. Potassium is not discussed in the guidelines for aquatic ecosystems, livestock watering and aquaculture.

BROMIDE (Br)

Bromide concentrations during all four trips were below the detection limit for bromide (<0.04 mg/L). There are no recommendations in the South African water quality guidelines on the target range for bromide in freshwater. Canton *et al.* (1983), however, found that bromide ion impairs the reproduction of crustaceans and fish and proposed a criterion for water quality of 1 mg/L. Concentrations of bromide in surface water regularly surpass this value, at times reaching levels which have acute effects on water organisms, but in the Panhandle there are no such threats from bromide.

NITRITE (NO_2) AND NITRATE (NO_3) AS INORGANIC NITROGEN (N)

Nitrite concentrations in the Okavango Panhandle were all below the detection limit of 0.01 mg/L. Twenty-three of the 48 readings for nitrate were below the detection limit of 0.02 mg/L, while the rest ranged between 0.04 and 0.55 mg/L (Fig 4.14). The highest concentration of nitrate was obtained at OR6 in July 2008. OR6 is situated in the mainstream at the first island downstream of Red Cliffs (Fig. 3.2).

Inorganic nitrogen concentrations of less than 0.5 mg/L are low enough to limit eutrophication and to reduce the probability of blue-green algae and other plant growth. The concentrations in the Panhandle illustrate just this. The water in the Okavango is not nearly eutrophic, which is one of the explanations why dissolved oxygen concentrations are so low. These low levels of inorganic nitrogen are perfect for the system as the inorganic nitrogen concentrations for a specific system should be based on the existing trophic status of that system and a target water quality range should be derived only after case- and site-specific studies. At such low concentrations it is clear that the Okavango is an oligotrophic system with a moderate level of species diversity. Such systems usually have a low productivity, rapid nutrient cycling and no blue-green algal blooms.

PHOSPHATE (PO_4)

Just as with bromide, all samples tested for phosphate indicated phosphate concentrations to be below the detection limit (0.1 mg/L). There are no target water quality ranges available for phosphate except that for fish. Concentrations of orthophosphates should not exceed 0.1 mg/L. In aquatic ecosystems, phosphorus is probably the main nutrient determining the level of eutrophication and the extremely low level of eutrophication in the Panhandle is just another indication of the low phosphorus levels in the system. Although high phosphorus levels can have toxic effects, a phosphorus shortage in fish, on the other hand, causes a poor appetite and the depression of growth. Furthermore, reduced bone calcification and cranial and skeletal deformities can occur in some species. Although phosphate concentrations in the Okavango Panhandle are low, it may be enough for the requirements of fish, because in unpolluted surface water,

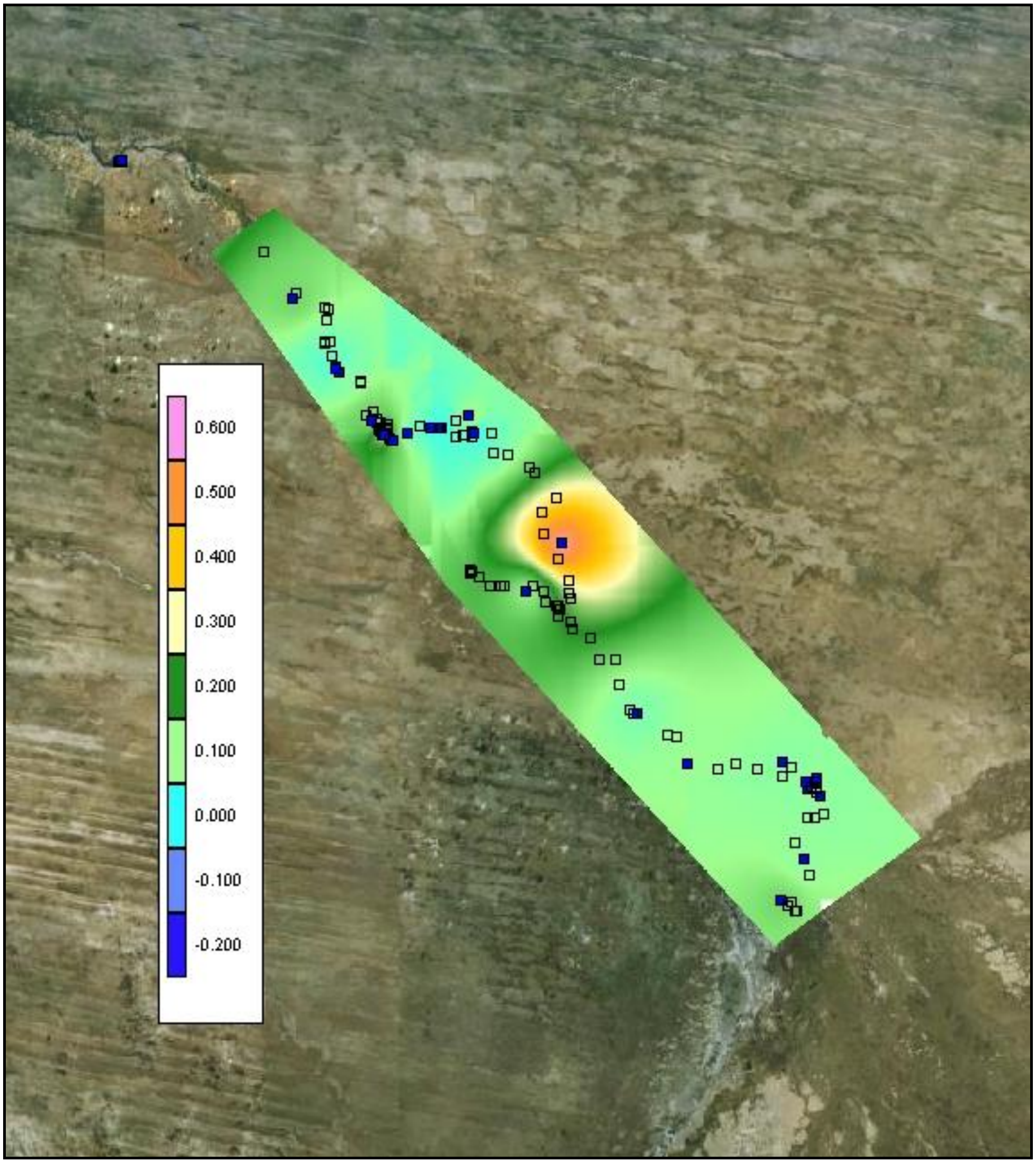


Figure 4.14: An extrapolated contour map illustrating the **nitrate** concentrations obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The turquoise and green areas represent concentrations below the detection limit of 0.02 mg/L, while the scattered cream colour and the orange area (OR6) represent values of between 0.04 and 0.55 mg/L.

concentrations may be as low as 1 µg/L. Nutrient-enriched waters, on the other hand, have phosphate concentrations of 0.3 mg/L or more.

SULPHATE (SO_4)

Almost all sites tested for sulphate indicated concentrations of less than 2 mg/L, except for five specific sites, which had concentrations between 2.77 and 4.47 mg/L (Fig. 4.15). Three of these five sites with concentrations higher than 2 mg/L are situated at Popa Falls (PF1, PF5 and PF7), while one was in Samochima Lagoon (SL2) and the other in the mainstream, far from human activity, between Red Cliffs and Nxamasere Channel (Fig. 3.2). All five of these samples were taken in July 2008.

In natural, unpolluted freshwater, sulphate concentrations are usually below 10 mg/L, most often in the region of 5 mg/L, so sulphate concentrations in the Panhandle are lower than typical concentrations for unpolluted water sources. Even the highest concentration (4.47 mg/L) found at OR6 (in mainstream, at first island downstream from Red Cliffs) is less than 5 mg/L. The target water quality range for domestic use is 0 to 200 mg/L, while for livestock it is 0 to 1,000 mg/L. Therefore, the water of the Okavango does not pose the threat of sulphate toxicity to humans or their livestock. No target water quality ranges are given for freshwater aquatic ecosystems or for aquaculture. Sulphate enters water naturally from the suspension of mineral sulphates in soil and rock and the mineral-poor Kalahari Sand over which the Okavango flows is probably the main reason why sulphate concentrations are so low. Furthermore, sulphates are discharged from acid mine wastes and many other industrial processes, which practically don’t exist in the Okavango.

TOTAL ORGANIC CARBONS (TOCs)

The total organic carbon (TOC) concentrations were quite high (23.30 – 71.80 mg/L) at some, but not all, locations in the Upper Panhandle (Fig. 4.16). The highest and third highest concentrations (71.80 and 64.70 mg/L) were obtained

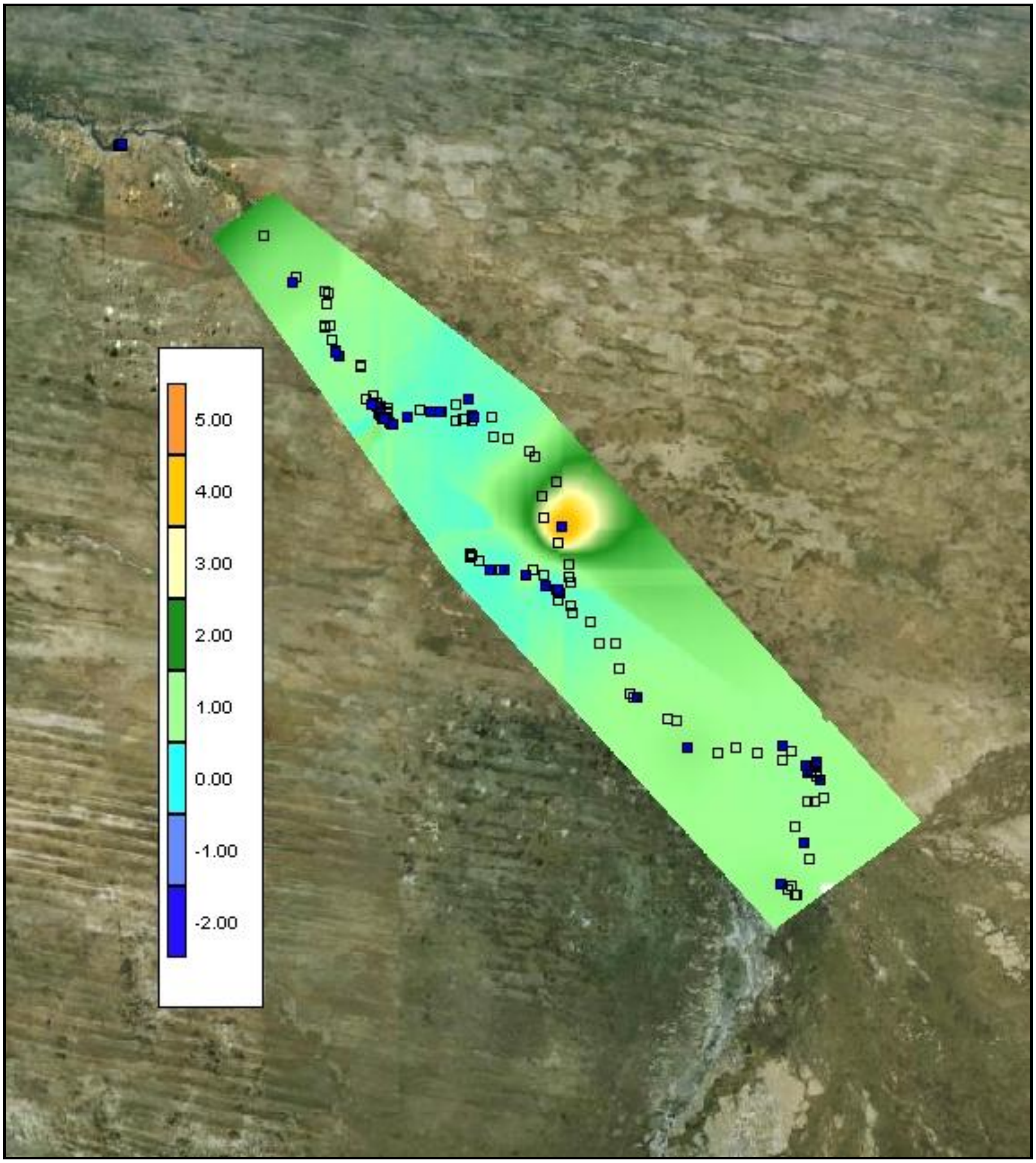


Figure 4.15: An extrapolated contour map illustrating the **sulphate** values obtained in the Okavango Delta Panhandle during December 2006, October 2007 and July 2008. The turquoise, light green and dark green areas represent values from 0.17 to 2.80 mg/L, while the orange area, in the mainstream (OR6), represents a value of 4.47 mg/L, sampled in July 2008.

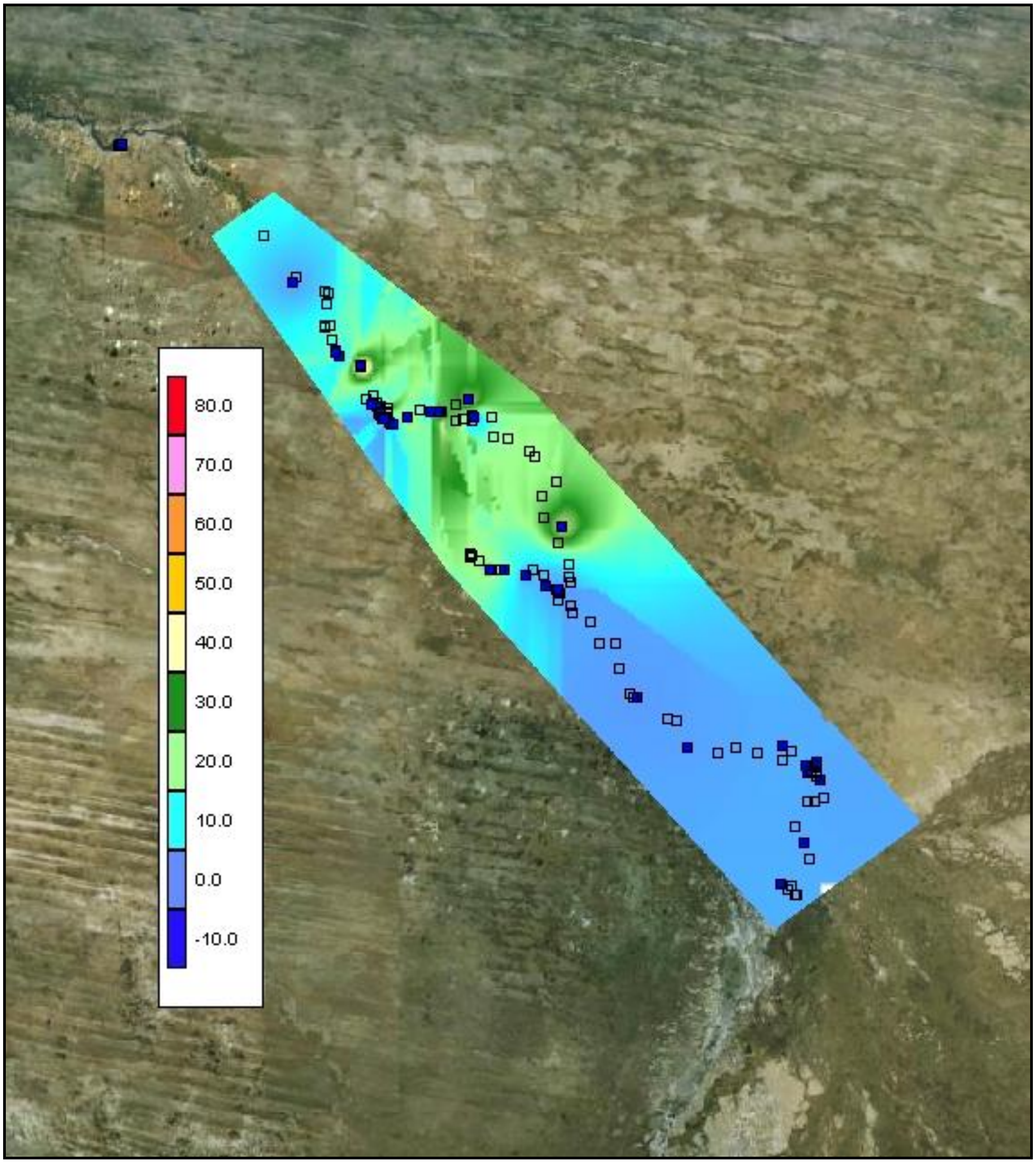


Figure 4.16: An extrapolated contour map illustrating the **total organic carbon** concentrations recorded in the Okavango Delta Panhandle during December 2006, October and November 2007 and July 2008. The blue areas represent values from 1.07 to 4.98 mg/L, while the turquoise areas in the Upper Panhandle represent values of 7.57 and 13.87 mg/L. The green and other colours represent concentrations from 23.30 to 71.80 mg/L, the latter being at OR91.

at OR91 and OR78, respectively, which are both situated within the Ngarange Channel. The second highest concentration (70 mg/L) was obtained at OR125, which is situated in Pelican Lagoon (Fig. 3.2). All three these samples were taken in December 2006. Despite the fact that there were a few high readings in the upper Panhandle, obtained during all three trips, the majority of the readings (35 of the 48 readings) during these trips were below 5 mg/L, which is the target water quality range for TOCs. In the Lower Panhandle all values were below 5 mg/L.

TOC is not discussed in any of the volumes of the South African Water Quality Guidelines (DWAF 1996a-d), but because it is the sum of dissolved and suspended organic carbon in water, it should give an indication of the DOC. The norms for DOC, on the other hand, are only given in the guidelines for domestic use and apply mainly to water that has already been treated for human consumption.

As already mentioned, DOC concentrations range from being non-toxic to extremely toxic, depending on the origin of the source. When DOC originates from natural humic acids of soil origin, for example, it is usually harmless and only of aesthetic concern, but if the DOC content includes synthetic organic compounds it may be considerably toxic. Synthetic organic compounds can be found in agricultural runoff after the use of pesticides, as well as from industrial effluents and domestic runoff. In areas such as Pelican Lagoon where a high concentration of TOC, and therefore, probably DOC, was obtained, it can only be of natural origin as the lagoon does not border dry land and it is distant from any human activity. The same counts for the Ngarange Channel and, thus, these organic carbons are probably harmless. Treatment, in any case, is not needed when one has consumed water with high DOC concentrations as it has no direct health implications, unless, however, there were toxic organic substances or sewage present.

COMPARISON WITH HART (1997)

When compared to the results obtained by Hart (1997) in 1986, not much has changed. Although Hart (1997) only sampled during one occasion (31 January to 7 February 1986) and in a small area in the Lower Panhandle around the village of Seronga, his results were very similar to the results of this study.

Hart (1997) found a pH range of 5.7 to 9.2 which is slightly bigger than what we found (6.09 to 7.38) over the entire Panhandle and beyond, with the exception of the Nxamasere Floodplains. However, the more alkaline result of 9.2 he obtained in an isolated pool at the eastern tip of Dungu Lagoon. He states that this was due to evaporative concentration as well as excretory inputs of the many cattle wading in the pool, as is the case in the Nxamasere Floodplains. If one removes the high pH values he obtained from the isolated pool, his range does not differ much from ours.

Hart (1997) also found the conductivity to be low (between 4.0 and 12.7 mS/m) as we did, although his results were slightly higher than those of this study (2.7 to 7.1 mS/m, excluding the Nxamasere Floodplains). Once again the highest values he obtained were from the isolated pool, just as we obtained higher values in the pools of the Nxamasere Floodplains. If this higher value, obtained by Hart (1997) in the pool at Dungu lagoon, is removed from his range, it is similar to ours. It is important to remember that Hart's (1997) study sites are included in this study, with the exception of the pool at Dungu Lagoon.

The water temperatures Hart (1997) found were also high (27 – 34 °C), although he found slightly higher DO saturations (20 – 220 %) than we did. Of all the chemical water quality parameters tested for in this study, Hart (1997) only tested for two, namely nitrite and phosphate. For nitrite he obtained concentrations of less than 0.01 mg/L, while for phosphate he got values below 0.1 mg/L. These values are below the detection limit for nitrite and phosphate and in this study they were below the detection limit as well.

Apart from the factors discussed previously concerning the microbiological quality of the water, it can be concluded that the water quality of the Okavango has not been negatively changed over the past 23 years and the water throughout the entire Panhandle and beyond, from Popa Falls to Guma Lagoon, is of an excellent quality. The DO saturation in the Okavango Delta is very low, but this is not necessarily a problem, as it has probably been that way for a very long time and organisms have evolved wonderful ways of coping with the oxygen deficit.

LAKE NGAMI WATER QUALITY

During 2004, Lake Ngami filled with water from the Okavango for the first time in decades (see Chapter 2). Since then it has been receiving water every year. The lake supports many bird species, as 90 species of waterbirds were recorded at Lake Ngami in the first year that it received water and in that same year more than 70 % (5,000) of southern Africa's Great White Pelicans were at Lake Ngami. Not only are there many species, but these species occur in great numbers, such as the 20,000 Red-billed Teal recorded in 2004. Lake Ngami, therefore, qualifies as an Important Bird Area under Birdlife's international criteria ([1]Personal communication). In October 2007 we sampled water at different points in Lake Ngami as well as in the Nchabe/Kunyere River which flows into the lake from the Okavango Delta.

In the Nchabe/Kunyere River at the village of Toteng the pH ranged between 7.61 [Toteng Bridge (TB)] and 7.95 [old Toteng Bridge (OTB)]. This is similar to the pH values obtained in the Panhandle. The conductivity in this river was found to be between 14.4 (TB) and 18.4 mS/m (OTB), which is more than that of the Panhandle, but similar to the conductivity of the Nxamasere Floodplains. This river was sampled at mid-day on a hot day during which the atmospheric temperature reached 34 °C. The water temperature was, therefore, high as well, between 28.5 (OTB) and 29 °C (TB). The DO saturation levels were higher in this

[1] Pete Hancock (Ornithologist & naturalist, Maun, Botswana).

river than most samples taken in the Okavango Panhandle, but were still quite low [between 67.66 (TB) and 71.67 % (OTB).

Lake Ngami is a very shallow water body and conditions in the lake itself were similar to those in the Nxamasere Floodplains and for the same reasons. Here, the pH was high, ranging between 9.65 (LN17P) and 10.16 (LNCamp1). The conductivity was found to be between 14.76 (LN17P) and 21.3 mS/m (LNCamp1) and water temperatures were extremely high, between 34 (LN17P) and 34.5 °C (LNCamp1). The DO concentrations are given in ppm because of the water temperatures that were so high. The table which one uses to compensate for temperature when converting values from ppm to % only gives values up to 30.9 °C. These concentrations were between 8.8 (LN17P) and 11.22 ppm (LNCamp1). Furthermore, chemical samples were also taken and results are indicated in table 4.5.

Table 4.5: Chemical water quality results obtained from Lake Ngami in October 2007. LN = different collection sites at Lake Ngami.

Site Name	**Ca (mg/L)**	**Mg (mg/L)**	**Na (mg/L)**	**K (mg/L)**	**P alk (mg/L)**
LN17P	8.490	1.626	11.242	4.800	0
LNCamp1	17.167	3.703	14.783	8.637	13
LNCamp2	13.863	3.396	12.660	6.631	0
Site Name	**M alk (mg/L)**	**F (mg/L)**	**Cl (mg/L)**	**NO_2-N (mg/L)**	**Br (mg/L)**
LN17P	58.7	0.19	0.93	<0.01	<0.02
LNCamp1	100	0.24	0.58	<0.01	<0.02
LNCamp2	82.4	0.22	0.95	<0.01	<0.02
Site Name	**NO_3-N (mg/L)**	**PO_4 (mg/L)**	**SO_4 (mg/L)**	**Turbidity (NTU)**	**TOC (mg/L)**
LN17P	0.02	<0.1	0.30	6.2	18.97
LNCamp1	<0.02	0.11	0.45	12.4	24.34
LNCamp2	<0.02	<0.1	0.25	9.93	19.51

Table 4.3: Chemical target water quality ranges, as set out in the South African Water Quality Guidelines (DWAF 1996a-d), for various uses.

CHEMICAL PARAMETERS	TARGET WATER QUALITY RANGE (TWQR)			
	Domestic Use	**Aquatic Ecosystems**	**Aquaculture**	**Livestock Watering**
Fluoride	0 - 1.0 mg/L	< 0.75 mg/L	NA	0 - 2 mg/L
Calcium	0 -32 mg/L	NA	NA	0 - 1000 mg/L
Magnesium	0 - 30 mg/L as Mg	NA	NA	0 - 500 mg/L
Sodium	0 - 100 mg/L	NA	NA	0 - 2000 mg/L
Chloride	0 - 100 mg/L	NA	0 - 600 mg/L	0 - 1500 mg/L
Potassium	0 - 50 mg/L	NA	NA	NA
Bromide	NA	NA	NA	NA
Nitrogen (Inorganic) (N+N+A)	NA	Must not change by > 15 %	NR	NA
Nitrite	0 - 6 mg N/L	See Nitrogen	0 - 0.05 mg NO2-N/L	0 - 10 mg/L
Nitrate	0 - 6 mg N/L	See Nitrogen	< 300 mg NO3-N/L	0 - 100 mg NO3/L
Ammonia	0 - 1.0 mg N/L	< 7 mg N/L	0.0 - 0.3 mg NH3/L	NA
Phosphate	NA	(Phosphorous) Must not change by > 15 %	0.1 mg/L orthophosphate	NA
Sulphate	0 - 200 mg/L as $SO4^{-}$	NA	NA	0 - 1000 mg/L
Total Organic Carbon	0 - 5 mg/L	NA	NA	NA
Dissolved Organic Carbon	0 - 5 mg C/L	NA	NA	NA

NA = Not Available. NR = Not Relevant.

Chapter 5

WHAT IS THE CONSERVATION CONDITION OF THE UNPROTECTED OKAVANGO DELTA?

Time and again we wonder how many of the pristine places left on earth we can protect from deterioration before it is too late, but we hardly ever wonder if there are in fact any pristine places left. Usually, terms like ‘pristine’, ‘wilderness’ or ‘wild’ have deep cultural roots and hard-to-translate differences in their local meanings. Let’s synonymise the word *pristine* to the words *wilderness* and *wild* and use it to refer to an area which is unaffected by humans and, therefore, containing native fauna and flora assemblages, which are presumed to still be unchanged since before human populations spread globally. Places like the Galapagos Islands, the Serengeti grasslands or the Caribbean coral reefs are considered to be pristine by the general public. Scientists, however, know that these places are actually highly disturbed. On the other hand, most scientists still consider some places to be pristine, because of the fact that they are remote from developed urban centres (Bortolus and Schwindt 2007). So is a remote region really a pristine region?

Although work was mainly done on the water quality of the areas of the Okavango Delta which are not protected by reserves etc., it is necessary to look at the impact certain issues can have on, not only the water quality, but the system as a whole. This will enable a better presentation of the conservation condition of the system as the title, ‘The Conservation Condition of the Unprotected Okavango Delta, Botswana’, suggests. The topics discussed in this chapter already do, or may some time in the future, have a negative impact on either the water quality, or the proper functioning of the Okavango Delta ecosystem, maybe even both. Therefore, these issues threaten the conservation of this marvellous wetland. Fortunately, there are various plans in place (also discussed in this chapter), which aim at ensuring that this resource remains as unspoilt as possible. Only time can tell if they will prove to be successful.

The Okavango Delta and River as a whole is usually termed ‘pristine’ and considered to be wild and unaltered, but is this really the case when one considers the definition of the word pristine? Yes, the Okavango does not have any major works such as dams along its water course and it is one of, and most likely the only of, Africa’s least altered aquatic ecosystems left. The sad reality, however, is that it currently faces many challenges and possibly many more in the future.

The substantial number of locals in and around the Okavango Delta are not the only people in the area, making use of, and placing pressure on, the natural resources. Tourism has grown tremendously in the past two decades, because of the Delta's rich wildlife diversity and scenic beauty.

TOURISM

The growing number of poor people in large parts of the world has caused the degradation of environments on a daily basis. Therefore, in environments such as the Okavango Delta, the development of tourism should improve environmental and human welfare, giving priority to the environment, as well as to the poor. The issue of sustainability in the development of tourism is related to the concept of eco-tourism, which is a type of tourism that:

- encourages conservation;
- has low impact from visitors;
- makes available opportunities for the beneficial involvement (social and economic) of local people; and
- makes visitors aware of environmental conservation (Mbaiwa 2003).

Not only in the Delta, but throughout the world, tourism is growing fast and it is most likely the world's largest industry, accounting for 6 % of the world's employment and about 5.5 % of its gross national product. International tourism grew faster in developing countries during the last decade. Marking the end of liberation wars and the establishment of democratic governments, southern Africa is now the fastest growing tourist destination in Africa (Mbaiwa 2003).

Mbaiwa (2003) states that Botswana is the third most visited country in southern Africa, after South Africa and Zimbabwe. Following the recent and current political instability and unrest in Zimbabwe, Botswana probably now lies second only to South Africa. In Botswana, tourist numbers increased from 644 000 in 1995 to 740 000 in 1998, with an annual growth rate of 13 %. In 2000, the Okavango Delta received 12.1 % of tourists arriving in Botswana, only Gaborone and Francistown receiving more, while combined visitors to Maun and the Okavango stood at 22.1 %.

Tourism supports economic development and this is the main reason why governments encourage tourism investment, especially in developing countries. Tourism in the Okavango Delta has become extremely popular, with activities such as safari hunting, game viewing, walking trails, *mekoro* safaris (Fig. 5.1A) and a number of other photographic activities. This has attracted tourists from various countries, resulting in the establishment of tourist facilities in Ngamiland (Mbaiwa 2003).

With the number of tourists increasing so tremendously in the Okavango recently, tourism activities are bound to have not only environmental, but socio-economic impacts as well. Locals and visitors can benefit from, amongst others, employment, exchange earnings and infrastructure development. Tourism can, therefore, promote national and regional development in Botswana (Mbaiwa 2003).

SOCIO-ECONOMIC IMPACTS

Mbaiwa (2003) discusses the socio-economic impacts of tourism in the Okavango Delta and found that tourism was important for gross domestic product (GDP) and government revenue, employment, infrastructure development and rural development. However, he also found that many socio-economic problems are related to tourism in the area.

Gross Domestic Product (GDP)

Botswana's gross domestic product (GDP) has increased tremendously due to the increase in tourism in, not only the Okavango, but other parts of northern Botswana (such as the Chobe National Park) as well. When in 1966 Botswana gained independence, tourism in the country was almost non-existent. Its contribution towards the country's GDP was, therefore, insignificant. Today, however, tourism is the second largest contributor towards the county's GDP after diamonds (Mbaiwa 2003).

Besides the revenues collected by government from import duties, taxes and licence fees, protected areas provide for much of the tourism income. From 1995 to 1999, for example, revenue collected from protected areas increased from P5,835,051 to P9,280,987, most of which came from Chobe National Park and Moremi Game Reserve. Botswana has nine protected areas of which the Chobe National Park is the largest generator of revenue, followed by the Moremi Game Reserve. Furthermore, Maun International Airport has become a major source of revenue for Ngamiland, as this is the landing destination of tourists visiting the Delta. Tourism has the potential to reduce Botswana's dependence on diamonds, the revenue earned from and export of which accounts for over 50 % of government revenue (Mbaiwa 2003).

Employment

There is no doubt that the increase in tourism in the Okavango Delta has increased employment opportunities for locals in the Ngamiland District. These people mainly obtain jobs at tourist facilities such as camps, lodges (Figs. 2.15E & F), transport, wholesale and retail industries. Studies conducted in March 2001 indicated that in 50 camps and lodges in the Okavango Delta, there were a total of 1,658 employees. Furthermore, in 35 tourism-related businesses situated in Maun, 727 people were employed (Mbaiwa 2003). There are many more camps, lodges and tourism-related businesses in Maun and in and around the Delta. Although it may sound like only a few jobs, it is significant in a third-world country, as each person with a job usually supports about ten other people.

Although employment is provided by tourism, locals in the Ngamiland Distrct mostly hold poor-quality, low paying jobs such as cleaners, kitchen hands, drivers, cooks, watchmen and those responsible for the skinning of wild animals during the hunting season. Only a few are employed as professional guides and assistant managers. Out of 42 managerial posts available at accommodation facilities in Maun, only six were occupied by Batswana managers. This is because accommodation facilities are mostly owned by foreigners. To top it all, Mbaiwa (2003) also found that, in the same position, there was a difference in wages between local staff and expatriate staff, locals earning between P350.00 and P1,000.00 and expatriates between P4,500.00 and P18,000.00. Of all the salaries received by local people in Maun, 62 % are below the poverty datum level of Botswana, which in 2003 was P954.78. All of this indicates that unless properly managed and controlled, tourism can be an exploitative industry to local people (Mbaiwa 2003).

Infrastructure Development

In order to support the booming tourism industry in the Okavango, infrastructure development has taken place rapidly since the 1990s. Prior to this, northern Botswana was practically inaccessible, with virtually no tarred roads. This all changes when government started to realise how important tourism in northern Botswana was for the economy of the country. During this period the Francistown-Kasane, Nata-Maun, Maun-Mohembo and Sehitwa-Ghanzi roads were constructed. Along the Delta, the Maun-Mohembo road provides a link with northern Namibia (Caprivi Strip). In the whole of northern Botswana the total distance of tarred roads adds up to 2,500 km. Tour operators and local people in Maun are of the opinion that this development and easier access has brought with it socio-cultural impacts such as crime, prostitution and the western influence on especially young people. This has brought about changes in the values, norms, identities and traditional ideas of the people in the area (Mbaiwa 2003).

Other than the tarred roads, the Maun Airport and air transport system was improved. This linked Maun and the Delta to other major cities which are on main routes used by tourists such as Johannesburg, Windhoek, Harare, Victoria Falls and Gabarone (Mbaiwa 2003). Mbaiwa (2003) comments that the Maun airport is one of the busiest airports, not only in Botswana, but in Africa, particularly during tourist peak season. He also mentions that the Ngami Times (2001) published an article stating that it is the second busiest international airport in Africa in terms of aircraft movements, with an average of 256 aircrafts landing and taking off each day during tourist peak season from April to October. The busiest being the Johannesburg area, which is a combination of Oliver Tambo, Lanseria, Rand and Grand Central.

In his study, Mbaiwa (2003) found that, at the time, there were 60 photographic lodges and camps in the Okavango region. These accommodation facilities included 554 rooms and 1,018 beds, an increase of 46.7 % from 1996. It is likely that they have increased even more during the past few years.

Law was passed in 2009, that all hunting concessions in and around the Moremi Reserve be changed to photographic concessions and that hunting should not take place in the region ([2]Personal communication).

Since most people in the region, who do have jobs, are employed by photographic tourist facilities, they play a major role in the socio-economic development of the Ngamiland District.

Rural Development

Construction, as well as the production of food and furniture, etc., is needed to be able to accommodate tourists in a region. This boosts local manufacturing and industry, as well as agriculture and has led to the establishment of a number of tourism-related businesses in the area, especially in Maun, Ngamiland's tourist centre (Mbaiwa 2003). These business opportunities can have a positive impact on rural development in the area of the Okavango Delta.

A variety of goods and services such as food in restaurants, spare parts in garages, petrol-filling stations and beverages in bars and bottle stores are provided to tourists and locals by the retail trade in Maun. Unfortunately, however, the majority of products are imported from Namibia, other regions of

[2] Prof. Liesl van As (Aquatic parasitology, University of the Free State, Bloemfontein).

Botswana and mostly from South Africa. This indicates that Ngamiland can not yet sustain itself and is dependent on outside economic influence. It is, therefore, not economically efficient (Mbaiwa 2003).

Tourism has been responsible for the establishment of social facilities such as banks and post offices in Maun, which is connected to the national electric grid for the provision of power. Furthermore, the telecommunications system in Maun has improved tremendously during the past decade. Not only are these services advantageous to the development of tourism in the region, but also to the local people, as it has encouraged local development (Mbaiwa 2003).

Concerning the socio-economic problems of tourism in the region, Mbaiwa (2003) claims that, unfortunately, tourism in the Okavango Delta has developed into ‘enclave tourism’. He gives the definition as: “tourism that is concentrated in remote areas in which the types of facilities and their physical location fail to take into consideration the needs and wishes of surrounding communities. Such tourist facilities are characterized by foreign ownership and are designed to meet the needs and interests of foreign tourists”.

This is indicated in Mbaiwa’s (2003) findings that of all the tourist facilities in Maun and the Okavango Delta, 81.5 % have foreign influence, while 18.5 % are fully owned by local citizens. Of the total number of tourist facilities, 53.8 % are 100 % foreign owned and 27.7 % are jointly owned by citizens and expatriates. In interviews with locals, Mbaiwa (2003) found that there was a general feeling that the Okavango Delta has been taken from them and given to foreign tour operators by the Botswana government. Locals are negative about the situation, as they see it as the ‘selling out’ of resources which originally belonged to them (Mbaiwa 2003).

ENVIRONMENTAL IMPACTS

Tourism can destroy that which drew the tourists to the destination in the first place, as it places additional pressure on the environmental resources upon which it is based. It all depends on the management thereof, if managed well, it can enhance or maintain the integrity of the environment, if mismanaged, destroy it. Mbaiwa (2003) found that tourism in the Okavango Delta had several small-scale environmental impacts on the wetland.

Creation of Illegal Roads

In the protected areas of the Delta, the creation of illegal roads by tourist vehicles is taking place, as government officials are not able to efficiently monitor the high number of tourists in the region. These roads are being created in some environmentally sensitive areas and affect the vegetation and scenic beauty of the Delta. The problem of illegal roads is intensified by the fact that camps and lodges are concentrated within certain small areas. This concentration of such facilities within a small radius indicates that there is not a proper management plan in place. Such a plan should include the best distance between facilities, which must be determined based on their ecological impacts (Mbaiwa 2003).

Noise Pollution

Noise pollution from engine boats, aircraft, vehicles and people disturb hippo populations, nesting birds and other wildlife species in the Delta. With the increase in tourism operations in the Delta, came the increase in small engine aircrafts, as well as airstrips. There are about 23 privately-owned airfields in and around the Delta from which planes are constantly taking off and on which they are regularly landing. Every time this happens birds and other wildlife are alarmed, plus the planes most often fly at very low altitudes. There are about eight privately-owned companies with more than 44 small engine airplanes carrying supplies and tourists around the Delta. Furthermore, the government has seven airstrips in the Delta, excluding those of the Botswana Defence Force (Mbaiwa 2003).

There are a large number of engine boats in the Delta, a total of 32 in the Xakanaxa area alone (Mbaiwa 2003). In a ten year period, from 1998 to 2008 more than 700 new boats were registered for the entire Delta (based on the registration numbers of our boats which were registered in 1998 and 2008). This may not sound like a lot, but it is building up, as not nearly so many boats retire during a ten year period.

The waves and noise, created by the fast movement of the boats, disturb nesting birds, as well as animals living in the water, such that hippos and crocodiles move out of busy areas. Population numbers can decline, such as when birds break eggs due to flying off suddenly when startled (Mbaiwa 2003).

In the Panhandle the number of boats on the river has increased tremendously during the past four years. Besides startling animals, the wakes of the boats erode the edges faster than they would normally be eroded. This causes riparian trees to end up in the river at a faster rate. Mbaiwa (2003) states that it was estimated that there were already about 111 boats in the Panhandle in 2001, with more or less 15 to 20 boats passing most parts of the river every day. Waterfowl are not only directly disturbed by the noise and presence of the boats, but indirectly as well, because the fish they feed on are disturbed and chased from nesting sites.

Littering and Sanitation

Littering and sanitation are also becoming major issues in the Delta and can alter the water quality negatively. Plastic bags and pieces of paper, cans and bottles are all often seen scattered along roads and on and around campsites. The amount of garbage in the Delta has increased substantially as a result of the increase in tourists visiting the wetland and is starting to have a negative impact on the environment (Mbaiwa 2003).

Groundwater Pollution

Furthermore, more people are permitted on the campsites than the ablution blocks can accommodate, exceeding their carrying capacities and design capabilities. This may have a negative impact on the environment as it may increase the potential for groundwater pollution. In some of the camps there are no septic tanks and ‘pit latrines’ are used. The same camps that get rid of waste and sewage effluent into the groundwater, rely on boreholes to supply them with water, creating the potential for drinking water contamination. The water table in the Delta is high, less than 1 m below the surface during flooding, and the sandy soils are very permeable, thereby allowing pollutants to travel much deeper. This leaves the potential for groundwater contamination by septic tank drainage high, especially where the groundwater levels are 10 m or less. If septic tanks are situated where the groundwater is 1 m or less below the surface, it can be contaminated by faecal bacteria such as *E. coli* and other pathogens. Thus, water may become dangerously polluted in and around the tourist camps and lodges of the Okavango Delta. Blue-green algae, blooms of which can be toxic, have been recorded in the system (Mbaiwa 2003).

FIRES

Vegetation fires are natural and they have been shaping landscapes across the world for ages. Fire is important in determining the diversity of plants as well as vegetation structure in the areas where it occurs. Since their origins, savannahs have been associated with fires, but recently humans have gained access to pristine areas, increasing the frequency of fires in areas where burning used to take place less often. Before human encroachment, fires in such areas used to depend on natural situations only, such as climatic variables and the accumulation of fuel loads (Heinl *et al*. 2007; Tacheba *et al*. 2009).

In the Okavango Delta, vegetation is burnt for a number of reasons such as: to stimulate the growth of new pastures; to clear land for cultivation; remove vegetation from waterholes or for better visibility when hunting. Unfortunately, many of these fires become out of control and run away accidentally (Mendelsohn and El Obeid 2004).

Man-made fires have been found to be connected to cultural practices and settlement distribution. For example, the Bayei culture mainly practices the harvesting of vegetation such as reeds and frequently uses fire to clear the floodplains in which these resources grow. Other cultures, on the other hand, avoid the use of fire, which causes damage to forage and crops, as they mainly practice the rearing of livestock and crop farming. The majority of illiterate Bayei continue with their burning activities even though there is a chance they could be convicted if caught. This is because they do not have conservation background, only their cultural beliefs, and therefore, are opposed to policies (Tacheba *et al*. 2009).

Burning is more widespread in Wildlife Management Areas (WMAs) than in communal areas due to the different land-use practices and policies. In WMAs, fire frequency is high where reeds and grass are collected, hunting safaris take place, where there are lagoons and floodplains popular for fishing and near camps and lodges which offer walking safaris and *mekoro* trips. In the areas strictly for photographic safaris, however, fire frequency is low. In communal areas, on the other hand, fires are only common where palm wine is harvested, while it is less frequently found where there is hunting, crop farming, livestock rearing or the collection of thatching grass. Ethnicity and literacy play a role, as hunting and thatching grass collection are practiced in both areas, yet fires are less common in communal areas (Tacheba *et al*. 2009).

Tacheba *et al*. (2009) state that the Okavango is the most fire-prone environment in Botswana and that the fires in this wetland are thought to be very damaging to the environment. Thus, practices associated with the use of fire have received strong criticism. The seasonal wetlands, floodplains and grasslands are the most fire-prone vegetation types, increasingly so are the more regularly inundated areas.

There is a theory that states that vegetation changes, after fire in fire-prone environments, are slight. In a study done on burned and unburned floodplains of the Delta, Heinl *et al*.'s (2004) findings supported this theory. They also found no specific plant trait to be favoured above others and that the most important changes were observed in vegetation height and cover or biomass production.

Due to its long history with fire, grasslands are not seriously affected by it. Heinl *et al*. (2007) state that in studies done on grasslands in southern Africa, it was found that fire frequency only had minor effects on the species composition, due to the general dominance of fire-tolerant species in such grasslands. Furthermore, Tacheba *et al*. (2009) mention a floodplain grass species found in the Okavango, which flowers after a fire event. Therefore, fires trigger at least one form of reproduction.

However, habitat types clearly respond differently and in a contradictory fashion to burning. Vegetation in an area with a higher fire frequency is commonly dominated by herbaceous plants, while woody plants are abundant where fires are less frequent (Heinl *et al*. 2007). Although Heinl *et al.* (2007) found no significant effect on typical savannah species, they did find that the major effect fires had on drying floodplains was the change in cover and abundance of woody species. Their studies indicated high tree mortalities for low, mid and high fire frequencies.

Runaway fires lead to the burning of massive areas every year and extensive damage to plants (Figs. 2.13D - F), causing several effects. Widespread grazing areas are lost and young trees are killed, such that in many areas there are basically no young trees of a number of valuable timber species. If fires are of high intensity, they may destroy below-ground biomass and plant propagules.

Other than the destruction of the timber trees, large areas become impenetrable thickets of shrubs, while soil fertility is reduced by the loss of nitrogen and sulphur to the atmosphere, as well as the burning of leaf litter and humus, which would normally have decomposed into organic nutrients into the ground. Furthermore, fierce fires could kill wild animals, livestock and people and the extent and frequency of burning in the Delta adds ash and carbon dioxide to the atmosphere (Mendelsohn and El Obeid 2004; Tacheba *et al*. 2009).

FISHERIES

There are 71 fish species in the Okavango Delta which range widely in size. Most, but not all, fish species are caught and those targeted are caught and consumed at all sizes by three different kinds of fishermen. Firstly, there are those who catch fish for recreation. These are mainly tourists who use rods and lines and normally go for trophy-sized fish, especially Tiger Fish and Large-mouth Tilapias (*Serranochromis*). The second type of fishermen are the commercial fishermen who own enterprises for the selling of fish. These are predominantly locals who fish with gillnets and aim at catching popular food fish such as Tilapia species (*Oreochromis* and *Tilapia*). The third, and by far the largest, group of fisherman are the subsistence fishermen. These people catch fish in order to feed their families and are usually from impoverished families (Figs. 2.14C & 5.1B) (Government of Botswana 2000).

The subsistence fishermen usually have limited access to socio-economic opportunities. Many of them do take on other livelihood activities, such as livestock sales and employment in the formal sector, but during difficult economic times they resort to fishing to support their livelihoods. Men, women and children catch fish. Women and children usually fish in groups, using baskets and fishing nets. They, therefore, generally catch the smallest fish species which can not be sold at the market and, thus, are consumed at home. Men mostly fish alone, making use of gillnets, hooks and lines and barrage traps. They catch the largest fish species which can be sold, bartered or peddled in and around the village for other household needs. The fact that most of the households (68 %) consume more than half of what they catch, indicates how important fishing is to their livelihoods (Mmopelwa *et al*. 2009).

The many different ways of fishing used by the local subsistence fishermen are not only for catching different species and different sizes of fish, but also for harvesting fish at different trophic levels and is the best strategy towards fish availability in the Delta. Due to the hydrological regime of the system, fish stocks are not always very abundant. During high floods fish are less abundant, while at low flood levels catch success is higher. This is probably due to a dilution effect, with the highest biomass being available between August and November and the lowest between March and May. This can be seen by the increase in fishing activities between September and December. During times of high fish stocks locals smoke or sundry fish, so that it can be consumed later when fishing is not as successful (Mmopelwa *et al*. 2009; Mosepele 2000).

Every year about 1,000 tons of fish are harvested from the Delta, but the fish stocks are not in danger of being over-exploited at present, due to the fact that large parts of the Delta can not be accessed for fishing. Fish can re-colonize the areas where fishing is taking place from the un-accessible areas. Furthermore, the variety of fishing gear used to catch many different species helps to prevent the skewing of the Delta's fish biodiversity and ecosystem function. By catching all species, one link in the ecosystem is not removed, leaving the others to thrive out of proportion (Government of Botswana 2000).

In 2008, new laws were brought into action by the fisheries section, under the Fish Protection Act. These laws compel anybody catching fish in the Okavango Delta to be in possession of a fishing permit, which may be valid for either a month or for a year. Those valid for a month cost P300, while those valid for a year cost P600. There is a reduced tariff for locals and tourist lodges must purchase a permit of P5,000 every year for their guests to be allowed to catch fish. Furthermore, December to January is closed season and nobody is allowed to catch any fish during these two months.

CATTLE AND GOATS OF THE DELTA

Cattle, goats and donkeys are the most abundant livestock in the Okavango, with more than half of the households in Kavango and Ngamiland owning these animals, some more, others less. There may be as many as 150,000 heads of cattle, 140,000 heads of goats and a large, but unknown, number of donkeys in the Okavango Basin, maybe even more. In Angola, however, cattle numbers are low due to various diseases in the area and the recent civil war, leaving most in Kavango and Ngamiland (Mendelsohn and El Obeid 2004). In the Okavango Ramsar site area there are about 193,997 cattle and 98,975 goats, the latter's numbers having tripled in the last 30 years ([3]Personal communication). Cattle numbers, too, in both Namibia and Botswana have increased tremendously over the past 100 years. This has mainly been due to more and more wealthy people acquiring herds, as well as the better control of diseases. Today, there are large herds of these animals in the southern part of the river in Kavango and the southern and western part of the Delta (Mendelsohn and El Obeid 2004), as well as at Lake Ngami.

Livestock, for obvious reasons, tend to congregate close to water and may cause serious damage to the natural environment. A good example of this is the major changes which have taken place throughout the Kalahari Desert since the introduction and rapid growth of the cattle industry. Thomas and Shaw (1991) explain that in the beginning cattle were trekked from the village where their owners lived to areas in which grazing or water was plentiful, but that this was replaced by providing permanent water holes by digging wells. Because cattle remained in close proximity to the waterholes, rings of range degradation were created around these watering points as cattle tended to graze there more often

[3] Prof. Cornelis Vanderpost (Human geography, GIS & monitoring, HOORC, University of Botswana, Botswana).

and trampled the natural vegetation. This is still the case throughout the Kalahari and to top it all, it causes the local water table to drop. Furthermore, in a semi-arid area, such as the Kalahari, the carrying capacity is not very high.

The same counts for the Okavango Delta, where extremely high densities of cattle, goats and donkeys are concentrated in and around the wetland, being allowed to graze in floodplains and trample this sensitive ecosystem. One of the negative effects they have on an area is: where livestock numbers are too high they replace wild herbivore herds, due to competition. The second is that by defecating in wetlands or water bodies they may have a negative impact on the water quality by enriching the water with nutrients as can be seen in the Nxamasere Floodplains and the pool sampled by Hart (1997) at Dungu Lagoon. Thirdly, by trampling a water body, livestock have a negative impact on the aquatic organisms of that system.

In 2006 and 2007 we collected zooplankton from Lake Ngami, since the Lake being dry for more than 20 years and being inundated again in 2004 provided us with the perfect opportunity to look at which species of zooplankters emerge after 20 years of drought and what the succession of zooplankton species is. In June 2008 we returned to Lake Ngami to continue sampling zooplankton and what we found was that the lake had almost entirely dried up again. The only remnant of water was a small section in the centre of the, otherwise barren, landscape. On its own this is not a problem as water from Angola is only expected to reach the lake by August and fluctuating water levels are normal. The problem, however, then and now, are the shocking number of cattle in the area. Hundreds of cattle encroach upon this water body to drink water and feed on the grass growing there (Fig. 5.1C), trampling the place to such an extent that we could not come within reach of the water to collect samples. These samples would in any case not have produced any plankton as none of these filter-feeders can survive in such murky water (Fig. 5.1D).

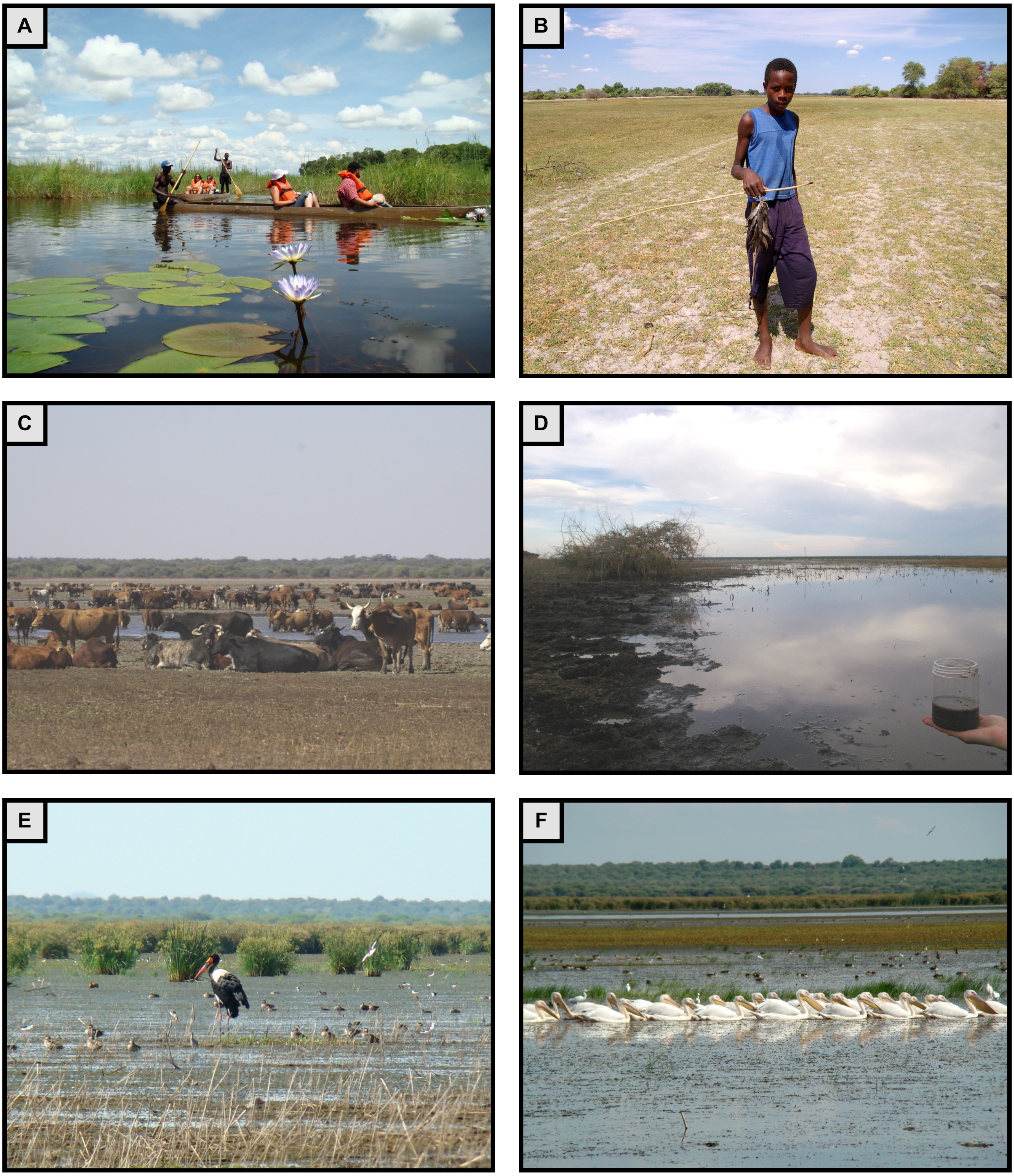


Figure 5.1: (A) Tourists on a *mekoro* safari. **(B)** Local boy at Nxamasere with his catch of the day. **(C)** Cattle encroaching upon Lake Ngami. **(D)** Murky/muddy water in Lake Ngami, due to trampling by cattle. **(E)** & **(F)** Lake Ngami is a spectacular wetland, rich in birdlife. **(B), (C) & (D)** Courtesy of the Aquatic Parasitology Research Group, UFS.

Due to the food supply zooplankton provide to most aquatic life, they are considered to be some of the most important organisms on earth, together with phytoplankton and bacterioplankton. Zooplankton are the food source for organisms at higher trophic levels and the sole prey item for almost all fish larvae and, therefore, can be considered secondary producers in an aquatic food chain. Furthermore, because of their high sensitivity to environmental change and change in water quality they make excellent indicators of environmental conditions. Therefore, with the number of cattle presently destroying this once spectacular wetland (Figs. 5.1E & F & Fig. 3.4B), Lake Ngami may never be given the chance to re-establish itself as a viable ecosystem.

The cattle industry in Ngamiland and the rest of Botswana poses at least two other problems for the Okavango and Botswana's wildlife.

VETERINARY CORDON FENCES

Dry spells are common in the Kalahari (see chapter 2) and cattle have succumbed to draught many times, particularly in the severe droughts of the 1930s and 1990s. Besides draught, the cattle industry in Botswana has also been affected by a number if disease outbreaks in the past. For example, in 1897 the rinderpest epizootic killed most cattle and large numbers of wildlife, not only in Botswana, but throughout most of southern Africa (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

The cattle industry grew again and then an epizootic of Contagious Bovine Pleuroneumonia (or lung sickness) broke out, reducing cattle numbers in the Kalahari from 350,000 in 1915 to 72,000 in 1926. After this, the cattle industry was affected by many problems such as the tsetse fly, which sucks blood from cattle and other animals, as well as from humans. In doing so, they transmit *Trypanosoma* parasites which cause sleeping sickness in humans and trypanosomiasis in cattle (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

Foot and mouth disease has also been a problem over the years, with outbreaks taking place in 1933-4, 1944, 1947-9, 1957-8, the 1960s and in 1977. Then in 1995, lung sickness (CBPP) broke out again in Ngamiland and along the whole northern Botswana border. So in 1996, about 320,000 cattle were slaughtered in Ngamiland to control the disease and protect other cattle to the south (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

The slaughtering of cattle has not been the only idea the Botswana authorities have come up with to control or eradicate the spread of the above-mentioned diseases. They act quickly, because beef exports to the European markets is a major source of economic income. Botswana receives 25 % more than the world market price for beef from Europe and to keep this up they have to comply with strict European Union (EU) beef regulations. These regulations stipulate that cattle must be disease-free (Ross 2003).

The first of several methods used to control diseases consists of vaccination campaigns, while the second is the construction of a series of fences to prevent or control the movement of cattle and the spread of diseases (Fig. 5.2A). A number of fences have been erected throughout the country since the 1950s (Fig. 2.16), which, until recently, has been done without environmental impact assessments (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

There have been frequent protests by environmentalists about these fences, as they fragment habitats and stop the movement of large game in search of foraging and water, causing the death of many animals. One of southern Africa’s greatest conservation tragedies took place in the vicinity of the Kuke Fence, which marks the northern border of the disease-free beef export zone. This fence stretches for about 300 km across the Kalahari, preventing animals, which usually turned to the Okavango during times of extreme drought, from reaching their giant waterhole. In so doing, it caused a massive die-off of wildebeest, about 95 % of the Kalahari's population, in the early 1980s. During these drought years animals migrated north as they usually do, but were channelled by the fence to Lake Xau, south of the Makgadikgadi Pans. At the time Lake Xau was dry and overgrazed and an estimated 50,000 of the 80,000 wildebeest that arrived there in 1983, died there, so that by 1986 there was no migration. The population had crashed and in aerial surveys done in 1987 only 260 wildebeest were counted in the central Kalahari. The great migrations were brought to an abrupt end with an estimated 300,000 wildebeest dying due to the barrier. Wildebeest were not the only victims, about 260,000 hartebeests and 60,000 zebra were amongst those that died along the Kuke Fence (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

Interestingly, a year before this tragedy took place (1982), the Gomare-Shorobe Fence, better known as the 'Buffalo Fence', was constructed around the south-western perimeter of the Delta Fan. This fence was constructed to protect cattle, so that they do not come into contact with the buffalo in the Delta, which might carry foot-and-mouth disease. It has, however, been of even greater benefit to the wildlife of the Delta, as it confines wild animals to the wetland, not separating them from grazing grounds and water and it halts the encroachment of the growing number of cattle and people into the Delta (Mendelsohn and El Obeid 2004; Ross 2003; Thomas and Shaw 1991).

After the lung disease outbreak in 1995, the government of Botswana built another series of fences in the region of the Delta, because it is thought that the disease came from the north in Angola and Namibia and that it mostly originates in Angola. The Samochimo, Ikoga and Setata Fences run parallel to one another from the western side of the Delta to the Namibian border (Ross 2003).

A group of environmental consultants were appointed by the government of Botswana to investigate the impact of cordon fences and in 2000 they released their findings, saying, amongst others, that the Setata Fence should be taken down, as a matter of urgency. They found that it only had a negative impact, serving no environmental, social or economic purpose. Surprisingly, the government agreed and had the fence taken down, only to pass legislation again in 2008 that it be re-erected. The new fence will run through certain WMAs, which are crucial migration roots for dry-region animals. These WMAs still carry healthy populations of elephant and other large herbivores and the re-erection of this fence will fragment the populations and block them from migrating from north to south, between the Okavango and their summer grazing areas (Michler 2008a).

The official reason for this sudden decision is a recent outbreak of foot and mouth disease, but it has been proved in the past that these fences do not prevent it from spreading. The real reason could, however, lie behind the fact that commercial cattle farmers who export to Europe, mainly consist of politicians who can write laws and people who hold other influential positions. Furthermore, they are supported by a cast of lawmakers in the EU. These cattle ranchers profit well from the preferential access Botswana's beef gets into European markets. Unfortunately, if this is not stopped, more and more fences will be erected and in no time, Botswana may not have wildlife populations left outside its conservation areas (Mitchler 2008a), which will be detrimental to the ecosystem as a whole.

The whole of Ngamiland should be declared a cattle-free area, which can actually be done, as tourism is the largest and most sustainable industry in the region. It creates employment, generates revenues and directly supports the livelihoods of many. Furthermore, places which are still wild, such as the Okavango, are becoming increasingly rare. If cattle are allowed to destroy the area it will be for the benefit of a few powerful people, but at the expense of the majority (Michler 2008a; Ross 2003).

INSECTICIDE SPRAYING

The impacts, connected to cattle, on the Okavango and its wildlife, do not quite end there. A long battle has been fought against the tsetse fly in the Okavango, because it causes trypanosomiasis in cattle and sleeping sickness in humans. Wild animals are quite immune to the disease, but livestock die easily. Tsetse flies were so well established in the Delta and posed such a threat to livestock that in 1942 a Tsetse Fly Control (TFC) Department was founded that lead to the destruction of huge areas of forest and large numbers of wildlife in the 1950s. Over 60,000 animals, particularly kudu and buffalo, were slaughtered around Maun in the 20 years following the establishment of this department. From 1966 they started with ground spraying of DDT (Dichloro-diphenyl-trichloroethane), which later changed to aerial spraying in the 1980s. In the 1990s the department started experimenting with odour-baited traps, which were black and blue in order to attract the flies and were soaked in an insecticide which kills them on contact. The traps are more environmentally friendly than spraying and so more than 50,000 of them were set out, but they were difficult to maintain. This lead to aerial spraying being used again in 2001 and 2002, in response to an outbreak of trypanosomiasis on the edges of the Delta in 1999 (Ross 2003; Thomas and Shaw 1991).

Nearly the entire Delta Fan, including the Moremi Reserve, was sprayed with deltamethrin from aeroplanes flying 10 to 20 m above the tree canopies. This spraying was very effective in controlling tsetse fly, but had a negative effect on the ecosystem by affecting non-target insect species and, therefore, possibly affecting insectivorous birds and other insect-eating species indirectly. It is very difficult to detect the effects that sub-lethal levels of toxins have on the environment, as these effects are difficult to distinguish from those of other factors such as weather and fire (Pendleton and Baldwin 2007).

Pendleton and Baldwin (2007) state that insects in mixed woodland trees declined by 44 %, while those in woodlands dominated by mopane trees decreased by 57 % during the 2002 spraying of the southern Delta Fan. Certain similar-looking species of beetles were mostly affected. Although insect numbers were reduced by about 50 %, they found no clear population declines in insectivorous birds within the following year. They do, however, state that sub-lethal doses of pesticides may cause feeding behaviour changes and weight-loss, thereby reducing reproductive success in birds and that further studies should be done to determine these long-term effects. Once again, action was taken for the sake of humans and their livestock, without consideration for the natural environment. Furthermore, pesticides are one of the main causes of water quality degradation and studies should be done on the water quality of the area being sprayed before and after the process.

DIAMONDS & DREDGING

One of the things that contributed to the die-off of the great wildebeest migrations, from central to northern Botswana, was diamond mining. Botswana is rich in diamonds, with nearly half of the major diamond-bearing Kimberlite pipes found in Africa, situated in this country. Diamond mining is the biggest contributor to Botswana’s GDP, with Botswana being the largest exporter of gem-quality diamonds in the world (Ross 2003).

In 1955 De Beers started searching for diamonds in Botswana with little success, until, years later, a few stones were found near the Makgadikgadi Pans. Termites had brought the diamonds to the surface, revealing a massive diamond pipe. In 1971, Debswana Diamond Company Limited (De Beers Consolidated Mines Limited at the time) opened the Orapa diamond mine, named after an isolated cattle post nearby (Reavell 1997; Ross 2003).

Mines need water and the Mopipi reservoir was built to store water from the Botetei River, which flows into the Makgadikgadi Pans from the Okavango Delta. When the severe draught started in 1979 and wildebeest migrated north, and finally east along the Kuke Fence, they reached Lake Xau and died there because it was dry. It had already been drained by the Orapa diamond mine to fill the Mopipi reservoir (Ross 2003).

Furthermore, the Boro River which flows into the Thamalakane River and subsequently into the Boteti, was dredged in order to increase the flow of the Boteti towards the mine. The dredging started in June 1971 and a 4.5 km stretch of river was dredged before the project was terminated in December 1974. What they aimed at doing was to deepen the channel by about 2 to 5 m, while straightening its meanders, and by depositing spoil heaps along the banks of the Boro, preventing water loss to surrounding floodplains (Reavell 1997).

In studies conducted from 1972 to 1975, Reavell (1997) found that the dredging of the channel increased the water's turbidity for about 12 km downstream. The suspended matter was released in pulses, while the dredger was active, but also when dredging had stopped after 1972. When the flood started rising in 1974, suspended matter was washed in from the spoil heaps, as these heaps were only covered by vegetation by 1976. The increase in turbidity below the dredged area decreased the depth of light penetration, thereby having an effect on the local plant communities. The conditions associated with that type of environment have deteriorated and so have both riverine and floodplain plant communities.

More recently, with the drying of the Boteti River and Mopipi reservoirs in the 1980s, there was a recommendation for further dredging of the Boro River. At this time the Southern Okavango Development Water Project arose, which included a plan to dredge the Boro River a further 50 km up into the Delta to increase flow, not only to fill the Mopipi reservoir, but also to supply Maun with water. It was also planned that dredging should cut through the Kunyere Fault, which holds back the Delta's water. The dug-out ground would be deposited along the sides, creating dam walls and thus, preventing the natural flooding of the surrounding floodplains and blocking the rivers small tributaries. This would also mean that roads would have to be built to allow for maintenance, opening previously inaccessible areas and decreasing tourism potential (Ross 2003).

Green Peace started the campaign ‘Diamonds are for Death’, resulting in De Beers, the main beneficiary of the project, withdrawing, but preparations still continued. Then, a short while before the project was to start, the local community, together with their chief and other prominent members, invited politicians to a kgotla held in Maun at which they all expressed how strongly they were sided against the Boro Dredging Project. A third and final factor, fortunately, resulted in the government cancelling the project and leaving the Okavango in peace. The World Wildlife Fund (IUCN) was invited to investigate the matter and after a year’s research, they too, expressed that they did not support it. The shelving of the Boro Project has been a huge conservation success as it would have had a tremendous impact on vast areas of seasonal floodplains, on water birds, animals, the breeding of fish, the access of people to wild foods and plants for medicine as well as on tourism and the normal functioning of the system. This can be seen in the impact that the droughts in the following few years had on the 4.5 km stretch dredged in the seventies. The trees and reeds died there and fish no longer breed in the area (Ross 2003).

The Boro Dredging Project was not, and will not be, the last attempt to abstract water from the Okavango Delta for development in this semi-arid region.

WATER ABSTRACTION AND DEVELOPMENT

Being a very dry country, Namibia’s water is an extremely valuable resource, whether for human needs or to sustain ecosystems. The demand for the Okavango’s water is not only big in the region of the river, but is increasing from outside the basin area.

Authorities are constantly striving to develop various possibilities to provide Windhoek, the country’s capital, with water. After poor runoff during the dry

1990s, Namibia reconsidered an earlier Master Plan developed in 1972. This plan proposed to build a pipeline of about 260 km from the Okavango River at Rundu to the town of Grootfontein, linking the river system with Windhoek. Currently, Namibia is in the last phase of this four-phased project known as the Eastern National Water Carrier (ENWC) project (Andersson *et al*. 2006; Ashton 2000; Kgathi *et al*. 2006).

The project has received a lot of attention in southern Africa and elsewhere and the impacts it may have on the natural environment of the floodplains in Namibia has been of concern, but the Okavango Delta in Botswana will probably be affected most (Diederichs and Ellery 2001). Botswana, too, is a dry country and not only does the Delta support livelihoods, but also an economically vital tourism industry. Stakeholders in Botswana are, therefore, concerned about how such a pipeline and other developments upstream may affect the Delta, paving the way for conflict over this resource (Andersson *et al*. 2006).

Ashton (2000) found that adverse effects on the river in Namibia will be small, while outflow to the Thamalakane River could be reduced by about 11 %. He states that there will be a loss of inundated area in the Delta, which will be concentrated in the lower reaches of the seasonal swamps and seasonally inundated grasslands, especially in the Boro, Gomoti, Santantadibe and Thaoge channels. The loss of permanently inundated area will be approximately 7 km² out of about 8,000 km².

On the other hand, Murray-Hudson *et al*. (2006) found that this loss of inundated area can vary between 4 km² during low abstraction and 165 km² during high abstraction. The reduction in inflows will take place during high and low flow periods and there will be an increase in the area of dry land. The size of the seasonal and occasional floodplains should not change, but the area they occupied will probably retreat towards the centre of the Delta. This will have an effect on wildlife habitat and biological productivity and, consequently, on livelihoods and tourism, not to mention the decreased outflow to Lake Ngami and the Makgadikgadi Pans.

Diederichs and Ellery (2001) explain that small changes in the hydrological regime of a wetland can cause significant biotic changes in emergent and submergent plant species. Such hydrological changes have a direct impact on the biotic response in wetlands, because of the physicochemical properties which are so easily altered. These properties include, amongst others, nutrient availability, soil salinity, sediment properties and pH. They go as far as to say that the Okavango River may become a seasonal river if abstraction takes place at low flow periods and that such conversions have proved to be ecologically disastrous in southern Africa. Their study showed that the vegetation of the floodplains in Namibia is determined by the complex interaction between hydrology, topography and disturbance history and that uniform abstraction will have a more severe impact at low flows. They recommend that, should abstraction take place, it be done during periods of high flow.

Furthermore, Namibia is also planning on constructing a hydropower plant at Popa Falls, near Divundu, which is expected to provide power to Rundu and Katima Mulilo. A recent study, undertaken by a team of consultants, to determine the effects the plant may have on the river, pointed out how important sediment transport is for the ecological functioning of the Delta and that the project may reduce the flow of sediments with a number of possible impacts on the Delta. These impacts include:

- a reduced rate of channel switching in the Okavango Delta Fan;
- the prevention of ecosystem renewal through the stabilisation of plant communities and as a consequence thereof;
- a reduction in biological diversity.

The study also recommends that the societal costs be weighed against the benefits of the project (Kgathi *et al*. 2006).

The impact of reduced channel switching may probably have the greatest detrimental effect of all the impacts mentioned above, as the changing channels help to keep the Delta's water fresh (see chapter 2).

There are presently no drastic plans for development in the Angolan portion of the basin, due to 27 years of civil war, which forced more than four million people to leave their homes. However, after the 2002 cease-fire, it is possible that many refugees will return to their homes in the basin, raising the need for development in order to fulfil their needs. Such developments may include urbanisation, industrialisation and hydropower schemes which may change the face of the basin. Agricultural practices may increase, raising the possibility of agricultural runoff and deforestation and there are many potential sites for the construction of dams in the Angolan portion of the basin (Andersson *et al*. 2006).

WATER SUPPLY

Access to basic water services is extremely important to human development across the world, yet at the start of the 21st century, a billion people worldwide do not have access to adequate drinking water. Similarly, two billion people still do not have access to proper sanitation. Numbers of woman and children, not only in Africa, but in the whole of the developing world, are still forced to walk long distances to collect untreated and sometimes impure drinking water from various sources. In Botswana, about 12.1 % of the population is without access to safe drinking water, which appears to be a praiseworthy achievement for a developing country (Swatuk and Kgomotso 2007).

The North South Water Carrier is situated along the Lobatse-Francistown road and facilitates access to safe drinking water for the majority of Botswana as about 80 % of the population is clustered within 50 km from this road. There are, however, questions regarding basic water provision in remote, rural areas, for example Ngamiland. In Botswana, Ngamiland included, groundwater resources constitute the main form of water supply, but they are not abundant as the recharge rates in the area are very low and over much of the Kalahari it is virtually zero. Furthermore, the groundwater, in some areas, is not of a very good quality, containing high concentrations of harmful substances such as fluorides and nitrates, as well as having high salinity (Swatuk and Kgomotso 2007).

In Botswana, water is public property and is controlled and allocated by the state. The Water Utilities Corporation (WUC) is responsible for urban water supply and the Department of Water Affairs (DWA) supplies water to major villages. The District Councils are responsible for small/medium rural villages and water services are only provided to officially recognised villages. In 1994, 21.5 % of Botswana's population was provided with water services by WUC, 22.5 % by DWA and 22 % by the District Councils, leaving 34 % without a reliable source of water. This 34 % of the population are those people who live in sparsely populated settlements, mainly cattle posts. They are responsible for their own water supply, which is usually fetched from major villages or towns or is obtained from privately owned boreholes and hand-dug open wells, as well as rivers (Swatuk and Kgomotso 2007).

A settlement has to be gazetted a village in order to be provided with water by the government and in order to be defined as a village it should fulfil certain criteria:

- It should consist of at least 500 people;
- The nearest village should not be more than 500 km away; and
- The settlement should have a headman and a Village Development Committee.

A three-tier hierarchy of primary, secondary and tertiary centres has been developed, Ngamiland only having one primary centre (Maun) and one secondary centre (Gumare) (Table 5.1). The rest of the settlements in Ngamiland are tertiary centres with the majority consisting of less than 249 people, which is far below the required level for gazettement (Swatuk and Kgomotso 2007).

Table 5.1: The hierarchical level of settlements according to their population ranges. Ngamiland has only one primary and one secondary centre (compiled from Swatuk & Kgomotso 2007).

Hierarchical level	Population range	Number of settlements in Ngamiland
Primary centres	20,000 - 100,000	1 (Maun)
Secondary centres	10,000 - 19,999	1 (Gumare)
Tertiary centres I	5,000 - 9,999	0
Tertiary centers II	1,000 - 4,999	12
Tertiary centres III	500 - 999	17
Tertiary centres IV	250 - 499	45

The minimum requirements in providing water to settlements include:

- There should be thirty litres of water available to each person per day;
- Water sources should not be further than 400 m from the homes of all the residents;
- Roughly 200 people should be served per standpipe with two taps;
- Storage facilities should be available to meet emergency requirements;
- There should be a back-up water source which can secure water availability, should main operational sources fail.

Water provided through standpipes is currently free to village inhabitants (Fig. 5.2B) and, with the exception of Maun, Ngamiland relies on the rural village water supply program for its services (Swatuk and Kgomotso 2007).

In Ngamiland, the pumping of groundwater is the most commonly used option, simply because it has been the least controversial of the supply practices. The villages without adequate water receive it by tanker trucks, which is a very expensive way of delivery and the sandy roads make access difficult as well.

Even though attempts are being made to supply these villages with water, most of them still experience seasonal shortages (Swatuk and Kgomotso 2007).

During the 2001 National Population Census, 26,313 households were located in Ngamiland, of which only 76.8 % have access to tap water. More than two-thirds (69.9 %) of the 76.8 % depend on communal stand pipes. The remaining 23.2 % of Ngamiland's population rely on other water sources, some of which collect water directly from the Okavango River and Delta (Fig. 5.2C) (Swatuk and Kgomotso 2007).

Even in recognised villages such as Maun, some people are not provided with water and rely on sources such as tankers, wells, rivers and streams. The water supplied to Maun comes from two wellfields, one of which has been depleted and will be decommissioned. In a survey conducted in Chobe (a middle-income suburb in Maun), almost three quarter of the people said that they experienced water shortages during the entire year, while almost 90 % said that water supply was unreliable and unpredictable. It is not uncommon that households go without water for several days. Most of the time it is due to unnecessary problems which could be avoided, such as leaving the borehole engines to run out of fuel. When this happens, people either have to travel to other places to get water, store water in containers or ask people with overhead storage tanks for water. Furthermore, the water's quality has been found to be poor and inconsistent (Swatuk and Kgomotso 2007). All this in the District Headquarters of Ngamiland and one of the wealthier suburbs.

For the 33 % of Ngamiland's population who live in villages of less than 500 people, the Okavango River (as well as its outflows) is extremely important as a source of water. Many of these people abstract and use untreated water from the rivers for domestic use. For example, 89 % of the people in ungazetted villages, along the Boteti River, abstract water directly from the River when it is flowing, the rest travel to gazetted villages to collect water from standpipes. When the river is not flowing during the dry season, or for the entire year during times of drought, most of the people get water from unprotected, hand-dug wells, which they usually dig within the river bed. Many a time, it is not possible to collect water, such as when there are crocodiles, hippos or elephant present. Water which is carried home from the Okavango is only used for drinking and cooking. People bath and do their laundry in the rivers and streams (Fig. 5.2D), leaving the potential for the water to be polluted (Swatuk and Kgomotso 2007).

The present study has shown that the water of the Okavango Delta, at least in the Panhandle, is safe for human consumption, except at certain locations where there may be contamination by coliforms of faecal origin (see chapter 4). The water should be safe to drink, but according to Swatuk and Kgomotso (2007), a member of parliament said at a kgotla meeting that some places like Maun Lodge and Riley's Hotel drain sewage straight into the Thamalakane River.

Ngamiland has serious water supply problems, with 48 % of the population in eastern Ngamiland and 28.2 % in western Ngamiland having had no access to piped water of any quality by 2001 (Swatuk and Kgomotso 2007). Although there are no statistics available on the present situation, it seems to have improved. In 2003 pipe systems were built at certain villages, such as Sepopa and Mohembo (bordering the Panhandle), with the pump station drawing water directly from the river (Fig. 5.2E). Such towns all received taps which provide water from tanks in which the water is stored (Fig. 5.2F).

The Ngamiland district is more dependent on natural resources to sustain livelihoods than any other district in Botswana. Therefore, the threat of water pollution by, amongst others, wastewater from villages and tourist facilities, bathing and doing laundry in rivers and streams, and floodplain gardening, is a potential danger (Swatuk and Kgomotso 2007).

Presently, there are no major water storage facilities in Ngamiland and the Okavango Delta has been considered as a source for water supply. In 1986 the

Figure 5.2: (A) Veterinary cordon fence checkpoint. **(B)** Children collecting water from a standpipe. **(C)** Locals collecting water from the Okavango River at Samochima fisheries. **(D)** Locals bathing in Samochima Lagoon. **(E)** Pump station at Sepopa. **(F)** Water tanks for storing water at Sepopa. **(E) & (F)** Courtesy of the Aquatic Parasitology Research Group, UFS.

government of Botswana planned on exploiting the surface waters of the Delta, but this was shelved after a negative Environmental Impact Assessment and protest by the public (see ‘diamonds and dredging’, this chapter) (Swatuk and Kgomotso 2007).

Never before has there been so many natural resource-use conflicts in the Okavango as at present, due to multiple users, interests and stakeholders. Farmers complain about wild animals and local people complain about their land being given to tourism industries, while conflict is increasing between recreational, commercial and subsistence fishermen. Furthermore, there is always the fear of water pollution. In response to these and other issues, the Okavango River Panhandle Management Plan (ORPMP) and the Okavango Delta Management Plan were produced in 2001 and from 2003 to 2006, respectively. The aim was to produce guidelines for proper management and utilization of the Okavango Delta resources (Magole 2008).

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THE OKAVANGO RIVER PANHANDLE MANAGEMENT PLAN (ORPMP)

The increasing population and urbanisation, as well as the culling of the region’s cattle have resulted in many social problems, such as poverty, in the Panhandle. There is also an increased interest in tourism in the Panhandle causing land-use problems. This, along with institutional issues, led to the Tawana Land Board initiating the ORPMP. Before this initiative, the Panhandle had no management plan and it was difficult to control land use and development, resulting in the conflicts (Magole 2008).

The production of the ORPMP was done as a consultancy for which the Land Board was the only sponsor, hence the project had a limited financial budget. Therefore, the consultants employed had only six months to complete the project and human resources were limited. As a result, the plan lacks basic planning characteristics and only deals with the natural resources available, not the relationship between these resources. There was also a limited investment in stakeholder involvement, especially communities, which led to there being little support for the plan. For example, it was proposed that a 500 m buffer zone be set along the river, which was so strongly opposed that the Land Board could not enforce it. There were instances when the Land Board itself ignored recommendations such as to stop allocating fields for arable agriculture and, therefore, many components and provisions of the plan were never put into practice (Magole 2008).

The ORPMP was flawed as a plan and a planning process and did not properly promote the conservation of the Panhandle, but it did result in the proper formation of another plan – the Okavango Delta Management Plan – which includes the entire Ramsar site (Magole 2008).

THE OKAVANGO DELTA MANAGEMENT PLAN (ODMP)

Currently, the Government of Botswana is undertaking the Okavango Delta Management Plan (ODMP) process, which was released in 2008 by the Ministry of Environment, Wildlife and Tourism. This is as part of the Government's commitment to the Ramsar Convention on Wetlands of International Importance, which states that Contracting Parties must formulate and implement planning to conserve the wetlands included in the list. The ODMP is an in-depth study of the Okavango Delta Ramsar Site (ODRS) and its primary goal is to integrate resource management for the Okavango Delta that will ensure its conservation over the long run and provide benefits for the well-being of people, in the present and the future, through the sustainable use of natural resources. This plan uses the ecosystem approach, which, amongst others, supports the involvement of stakeholders in managing natural resources. The publication of the ODMP was well-timed because the leases granted in 1994 were due for renewal last year (2009). The ODMP will serve as a fundamental working guideline for government and private-sector planning, both at national and regional levels (Magole 2008; Michler 2008b).

In the report it is stated that Lake Ngami should be declared a sanctuary which will provide the local community a stake in eco-tourism. It will also regulate the increasing number of tourists, as well as protect the bird populations from hunters and is, therefore, a move that can truly be applauded (Michler 2008b).

OKACOM

Listing the Okavango Delta as a Ramsar site in 1997, not only placed pressure on Botswana to develop a plan for its management, it also placed international focus on the activities in the area. However, managing the use of its resources is complicated by the fact that it is a transboundary river system which requires cooperation from all three basin states.

By signing the “OKACOM Agreement” in Namibia’s capital, Windhoek, in 1994, the three countries sharing the Okavango River Basin (Angola, Namibia and Botswana) recognised that it should be managed as a single entity. “The Agreement commits the member states to promote coordinated and environmentally sustainable regional water resources development, while addressing the legitimate social and economic needs of each of the riparian states”. All three countries realise that any developments upstream of the river can have considerable impacts on the resources downstream (OKACOM 2007).

On OKACOM’s (2007) website the objectives and role of the agreement is described as follows:

“The OKACOM Agreement establishes the Permanent Okavango River Basin Water Commission (OKACOM), whose objective is ‘to act as technical advisor to the Contracting Parties (the Governments of the three states) on matters relating to the conservation, development and utilisation of the resources of common interest to the Contracting Parties (basin member states) and shall perform such other functions pertaining to the development and utilisation of such resources as the Contracting Parties may from time to time agree to assign to the Commission'. The role of OKACOM is to anticipate and reduce those unintended, unacceptable and often unnecessary impacts that occur due to uncoordinated resources development. To do so it has developed a coherent approach to managing the river basin. That approach is based on equitable allocation, sustainable utilisation, sound environmental management and the sharing of benefits. The 1994 OKACOM Agreement gives it legal responsibility to:

- Determine the long term safe yield of the river basin;
- Estimate reasonable demand from the consumers;
- Prepare criteria for conservation, equitable allocation and sustainable utilisation of water;
- Conduct investigations related to water infrastructure;
- Recommend pollution prevention measures;
- Develop measures for the alleviation of short term difficulties, such as temporary droughts; and
- Address other matters determined by the Commission"

THE BIOKAVANGO PROJECT

Furthermore, projects are underway which may also play a role in the conservation and sustainable development of the Okavango Delta, such as the BIOKAVANGO project. On this project's website (BIOKAVANGO project 2009), the aims, objectives, strategies and focus of the project are described shortly. The following four paragraphs are quoted from BIOKAVANGO project (2009).

"The BIOKAVANGO Project's aim is to lift barriers to mainstreaming biodiversity conservation objectives into the activities of three production sectors: water, tourism and fisheries, all dependent on ecological services and goods provided by the Okavango wetland system. The Project is funded by the Global Environment Facility (GEF) and the Government of Botswana, and implemented by the Harry Oppenheimer Okavango Research Centre (HOORC) in Maun. Project design is founded on the recognition that command and control approaches alone are inadequate to ensure effective and sustainable mainstreaming of biodiversity management objectives in the production sectors of the Okavango Delta."

"The project has therefore adopted a two-pronged strategy to mainstreaming biodiversity management in the three sectors, namely:

- transferring certain key responsibilities for biodiversity management to land users ensuring that land use activities are undertaken with due diligence to conservation objectives and

- building capacity within the regulatory authorities responsible for resource use allocation and management to assimilate and apply biodiversity management objectives in decision making."

"The project focuses on sectors dependent upon the sustainable use of biodiversity, where the investment risk associated with the erosion of ecological integrity within the wetland is accordingly high. Interventions are focused on realizing conservation gains without compromising sectoral activities and profitability."

"Interventions have been designed to contribute to four complementary outcomes namely:

- Enabling environment strengthened at both systemic and institutional levels.
- Biodiversity management objectives integrated into the water sector.
- The tourism sector is directly contributing to biodiversity conservation objectives in the Okavango Delta.
- Biodiversity friendly management methods are inducted into fisheries production systems."

CONCLUSION

Despite all the mistakes and bad decisions that have been made in the past and all the changes taking place so rapidly in and around the Okavango Delta, it still remains one of the most beautiful and pristine natural wonders to date. The water quality of the unprotected Panhandle remains unaltered after 23 years of change and growing pressure placed on it. However, this does not mean we can afford to continue leaving it unmanaged, because one big enough error may be the final stone removed before everything falls apart. The Delta provides so many goods and services on which, not only plants and animals, but also humans, in the semi-arid Kalahari Desert rely.

Over the past few decades human populations in and around the Okavango River, in all three basin states, have grown remarkably, especially in the Angolan portion, following the end of the civil war. The population growth has brought with it an increase in the number of cattle, goats and donkeys. Spraying has taken place to control diseases transmitted to humans and livestock by the tsetse fly. The substances sprayed do not only target tsetse flies, but may be harmful to other fauna and flora, especially insects and insectivorous species. Veterinary cordon fences have been erected to control the spread of cattle and, thereby, control the spread of foot-and-mouth and other diseases. These fences have cut wildlife off from their dry season haven and have caused the die-offs of huge herds.

Due to the recent building of roads in Ngamiland, tourism has grown especially fast. This has brought even more people to the area and is causing socio-economic as well as environmental problems, including possible groundwater pollution. Although tourism does contribute considerably to the country's GDP, it has the potential to destroy exactly that which people come to the area to see and experience, especially if not well managed. Tourism could be key to protecting the Delta, provided the right steps be taken to implement management plans and control the number of tourists residing in the Delta at any given time. The number of boats and planes should be controlled in a stricter manner as well. The activities of tourists and tourism operators should constantly be monitored in order to maintain control. I recommend that tourist prices be raised and in so doing Botswana can afford to allow only a certain amount of tourism operations and only a limited number of tourists at a time. With such a system in place, however, it is necessary that local people, not only those from Botswana, but also the rest of the SADC countries, should get special, affordable rates, so that the high costs involved in visiting the Delta do not deprive residents of their own natural wonders.

Other than the fact that the large numbers of livestock in the unprotected portion of the basin are destroying floodplains by trampling the place and defecating in the water, these animals also have the ability to destroy the tourism potential of the area. It can be argued that the Moremi Reserve is a protected area from which cattle are kept out, but what happens upstream, such as in the unprotected Panhandle, affects what happens downstream. It is because of this that water abstraction upstream in Namibia and Angola may possibly affect the Delta in Botswana more than it seems. The annual pulse flooding and subsequent fluctuating water levels and changing channels are really what drives the system and keeps the water fresh and because of this, the construction of dams (which hold back water and sediment) is probably the most harmful change that can be brought about.

Mining, too, has left its mark in the Delta with the dredging of the Boro River. Fortunately, the Delta has escaped destruction despite all the negative activities which have taken place in the past. The overall water quality has not changed over the past 23 years and the wetland has managed to maintain its ecological integrity. Water throughout the unprotected Okavango Panhandle is fit for human consumption, without prior treatment, as all physical and chemical water quality parameters fell well within the target water quality ranges for various uses. However, caution should be taken in areas close to human activity, as the water in these areas could potentially be contaminated with faecal bacteria.

It is safe to say that, at present, the Okavango is in an excellent state and that the water quality of the system is in an extremely good condition, despite heavy change taking place in the entire basin. However, future development, such as the Eastern National Water Carrier project, dams and hydropower plants, as well as further dredging and constantly growing numbers of locals, tourists and livestock may lead to the Okavango Delta losing its *pristine* status.

Chapter 6

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* Source not seen in original form.

Abstract & Opsomming

ABSTRACT

The Okavango River lies within the semi-arid Kalahari Desert of southern Africa and is an extremely important source of food and water. This river ends in an inland delta in Botswana which supports the livelihoods of thousands of people, some of whom rely directly on the river for survival. The Delta is one of the largest Ramsar sites in the world and is thought to be amongst the only pristine places left on earth. The eastern Delta fan is a protected area, the Moremi Reserve, whilst the Panhandle, the western Delta fan and Lake Ngami are unprotected. In the mid-eighties a limnological study of the Okavango Panhandle was undertaken by Rhodes University. Against this background the following questions were formulated: how did human activities change in the unprotected Okavango Delta during the past 23 years; how did it influence the water quality of the system and how did it affect the ecological integrity of the system, if at all? Using the limnological profile as baseline, not only were the study sites revisited and water quality measurements repeated, but samples were taken all the way from Popa Falls in Namibia to lagoons in the north-western Delta fan and at Lake Ngami. Despite the increase in human activities and livestock, physical water quality parameters lie within the ranges as set out in the Water Quality Guidelines of South Africa, while most chemical substances are below detection limit. The microbiological water quality should be studied in more detail. The Okavango Delta is a dynamic, yet fragile, ecosystem and projects such as the proposed hydroelectric plant and the Eastern National Water Carrier project may have adverse effects. Livestock and the erection of veterinary cordon fences, amongst others, have proved to be detrimental to the system.

OPSOMMING

Die Okavango Delta is in die Kalahari Woestyn in suider Afrika geleë en is ‘n baie belangrike bron van voedsel en water in die area. Die rivier eindig in ‘n binnelandse delta in Botswana. Die lewenswyse van duisende mense word deur die rivier ondersteun en baie is direk van die rivier vir hul bestaan afhanklik. Die Delta is een van die grootste Ramsar gebiede ter wêreld en is een van min oorblywende ongerepte wildernis gebiede. Die oostelike Delta area is ‘n bewaringsgebied, die Moremi Reservaat, maar die Panhandle, die westelike Delta area en Ngami Meer is nie bewaringsgebiede nie. In die middle tagtig’s het die Universiteit van Rhodes ‘n limnologiese studie oor die Okavango Panhandle uitgevoer. Teen die agtergrond is die volgende vrae geformuleer: hoe het menslike aktiwiteite gedurende die laaste 23 jaar in die onbeskermde gebiede van die Okavango Delta verander? Hoe het dit die waterkwaliteit van die stelsel beinvloed en hoe het dit die ekologiese integriteit van die stelsel beinvloed? Deur die limnologiese verslag as basis te gebruik, is die studie gebiede weer besoek en water kwaliteit opnames by die punte herhaal. Bykomende monsterpunte is ook vanaf Popa Valle in Namibia tot by lagunes in die noordwestelike gedeelte van die Delta, asook by Ngami Meer, geneem. Al was daar ‘n verhoging van menslike- en vee-aktiwiteit in die gebiede, was fisiese waterkwaliteits-parameters nogsteeds binne die grense wat deur die Water Gehalte Riglyne van Suid Afrika voorsgeskryf word. Meeste van die chemiese stowwe is laer as die opsporings limiet, maar die mikrobiologiese waterkwaliteit moet meer in diepte bestudeer word. Die Okavango Delta is ‘n dinamiese, maar sensitiewe, ekosisteem en projekte soos die beplande hidroelektriese eenheid en die Oostelike Nasionale Waterdraer projek kan nadelige gevolge op die stelsel hê. Vee en die bek en klouseer heinings, onder andere, het bewys dat dit nadelige uitwerkings op die stelsel het.

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Appendix

Appendix 1: Sampling site names and GPS coordinates for each site.

SITE NAME	GPS COORDINATE
Drotsky	S18 24.726 E21 53.305
DW60/SL1	S18 25.319 E21 54.070
GUMA	S18 57.348 E22 22.404
KAMAISL	S18 19.542 E21 49.580
NX3	S18 34.978 E22 00.032
NX4	S18 35.224 E22 00.095
NX6	S18 35.477 E22 00.642
Nxamalodge	S18 36.416 E22 05.272
OR10	S18 37.664 E22 06.492
OR100	S18 38.559 E22 07.267
OR101	S18 25.848 E21 53.801
OR102	S18 25.879 E21 53.775
OR103	S18 25.890 E21 53.763
OR104	S18 25.888 E21 53.761
OR105	S18 25.875 E21 53.741
OR106	S18 25.853 E21 53.742
OR107	S18 25.853 E21 53.738
OR108	S18 25.847 E21 53.734
OR109	S18 25.837 E21 53.745
OR11	S18 38.940 E22 07.318
OR110	S18 25.836 E21 53.748
OR111	S18 07.329 E21 34.804
OR112	S18 07.307 E21 34.822
OR113	S18 07.269 E21 34.934
OR114	S18 07.315 E21 34.973
OR115	S18 07.222 E21 34.992
OR116	S18 25.311 E21 57.168
OR117	S18 26.228 E21 54.390
OR118	S18 25.563 E21 53.609
OR119	S18 22.249 E21 52.166
OR12	S18 39.616 E22 08.662
OR120	S18 25.020 E21 53.531
OR121	S18 26.220 E21 54.395
OR122	S18 25.734 E21 55.471
OR123	S18 25.389 E21 57.606
OR124	S18 25.817 E21 59.590
OR125	S18 25.346 E21 57.775
OR128	S18 38.141 E22 06.4
OR129	S18 44.438 E22 11.504
OR13	S18 41.111 E22 09.349
OR130	S18 44.463 E22 11.538
OR131	S18 36.042 E22 02.480
OR132	S18 36.032 E22 01.426
OR133	S18 35.141 E22 00.112
OR134	S18 17.233 E21 49.533
OR135	S18 16.210 E21 47.435
OR136	S18 21.242 E21 50.326
OR137	S18 22.156 E21 52.104
OR138	S18 24.515 E21 52.570
OR139	S18 25.003 E21 53.321
OR14	S18 41.058 E22 10.438
OR140	S18 21.285 E21 50.305

SITE NAME	GPS COORDINATE
OR141	S18 26.124 E21 54.246
OR142	S18 25.356 E21 53.381
OR143	S18 25.414 E21 53.401
OR144	S18 25.092 E21 54.062
OR15	S18 42.781 E22 10.693
OR16	S18 44.730 E22 12.000
OR17	S18 46.153 E22 14.174
OR18	S18 46.283 E22 14.848
OR19	S18 48.068 E22 15.624
OR2	S18 27.957 E22 04.224
OR20	S18 48.433 E22 17.902
OR21	S18 48.100 E22 19.091
OR22	S18 48.445 E22 20.649
OR23	S18 48.908 E22 22.482
OR24	S18 49.788 E22 24.331
OR25	S18 49.402 E22 24.875
OR26	S18 51.462 E22 25.508
OR27	S18 51.785 E22 24.816
OR28	S18 51.727 E22 24.286
OR29	S18 53.511 E22 23.390
OR30	S18 55.628 E22 24.477
OR31	S18 58.070 E22 23.603
OR32	S18 57.734 E22 22.953
OR33	S18 57.489 E22 23.203
OR34	S18 58.130 E22 23.464
OR35	S18 54.550 E22 24.072
OR36	S18 49.017 E22 24.923
OR37	S18 49.306 E22 24.889
OR38	S18 49.300 E22 24.100
OR39	S18 50.217 E22 25.224
OR3REDCLIF	S18 28.330 E22 04.557
OR4	S18 30.092 E22 06.137
OR40	S18 49.986 E22 24.994
OR41	S18 49.788 E22 24.868
OR42	S18 48.334 E22 23.070
OR43	S18 48.010 E22 22.492
OR44	S18 49.618 E22 24.497
OR45	S18 36.491 E22 04.062
OR46	S18 36.101 E22 04.521
OR47	S18 37.437 E22 06.165
OR48	S18 37.671 E22 06.415
OR49	S18 27.156 E22 02.725
OR5	S18 32.495 E22 05.307
Or50	S18 26.992 E22 01.619
Or51	S18 25.724 E22 01.579
OR52	S18 25.888 E22 00.085
OR53	S18 25.905 E21 58.915
OR54	S18 13.336 E21 45.212
OR55	S18 16.596 E21 47.277
OR56	S18 19.604 E21 49.502
OR57	S18 18.081 E21 49.682
OR58	S18 17.272 E21 49.765

Appendix 1 (continued): Sampling site names and GPS coordinates for each site.

SITE NAME	GPS COORDINATE
OR59	S18 19.512 E21 49.928
OR6	S18 33.111 E22 06.555
OR60	S18 20.470 E21 50.078
OR61	S18 21.516 E21 50.553
OR62	S18 24.318 E21 53.094
OR63	S18 24.856 E21 52.981
OR64	S18 25.014 E21 53.539
OR65	S18 25.144 E21 54.077
OR66	S18 26.179 E21 54.413
OR67	S18 25.661 E21 55.497
OR68	S18 25.329 E21 57.847
OR69	S18 25.319 E21 57.796
OR7	S18 34.274 E22 06.297
OR70	S18 25.355 E21 57.931
OR71	S18 24.480 E21 59.879
OR72	S18 25.588 E22 00.052
OR73	S18 25.672 E22 00.148
OR74	S18 24.856 E21 58.999
OR75	S18 25.866 E21 59.503
OR76	S18 25.382 E21 57.634
OR77	S18 21.302 E21 50.277
OR78	S18 24.484 E21 59.878
OR79	S18 25.111 E21 54.086
OR8	S18 35.697 E22 07.065
OR80	S18 25.284 E21 57.782
OR81	S18 25.288 E21 57.819
OR82	S18 25.337 E21 57.103
OR83	S18 25.349 E21 54.083
OR84	S18 25.396 E21 54.130
OR85	S18 25.421 E21 54.039
OR86	S18 25.430 E21 53.442
OR87	S18 25.441 E21 53.552
OR88	S18 25.444 E21 53.432
OR89	S18 25.453 E21 53.582
OR9	S18 36.963 E22 07.190
OR90	S18 25.481 E21 53.509
OR91	S18 25.668 E22 00.292
OR92	S18 25.691 E21 53.670
OR93	S18 25.788 E21 53.905
OR94	S18 25.832 E21 53.754
OR95	S18 31.029 E22 05.191
OR96	S18 36.049 E22 02.268
OR97	S18 36.575 E22 07.110
OR98	S18 37.112 E22 05.404
OR99	S18 37.360 E22 06.281
PF1	S18 07.330 E21 34.799
PF2	S18 07.228 E21 34.875
PF3	S18 07.232 E21 34.886
PF4	S18 07.234 E21 34.901
PF5	S18 07.293 E21 34.910
PF6	S18 07.317 E21 34.971

SITE NAME	GPS COORDINATE
PF7	S18 07.235 E21 34.994
SL2	S18 25.828 E21 53.787
SwampStop	S18 44.748 E22 11.793
XARO	S18 25.235 E21 56.390