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Josephine Phillip Msangi *Editor*

Combating Water Scarcity in Southern Africa

Case Studies from Namibia

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To my children Zilaoneka, Anna, Geoffrey and James whose love, care and support keep me going

Preface

The topic of water scarcity conjures the impression that it is a well trodden path, because so much has been written and many comments made on water deficits around the globe particularly in desert, arid and semi-arid landscapes and during droughts. However, water scarcity should be distinguished from aridity because water scarcity describes the situation where the available water quantities are inadequate to meet normal activities even in areas outside arid areas and deserts. Water scarcity can be caused by mismanagement of available water so that it is not available to users; mismanagement that ruins potable water so that it is unusable. Water scarcity is a relative concept and can occur at any level of supply or demand. Water scarcity fluctuates over time and space; it is a function of supply and demand both sides of the equation being shaped by social set up, political choices and public policies of any given country.

While aridity cannot be reversed, water scarcity can be reversed through manipulation of water potability through wise usage and improved management of the available water, management that increases access and prevents pollution or excessive losses through evaporation. The approach used in this book is to bring to the fore how Southern Africa region has embarked on interventions that address this aspect of water scarcity.

The first chapter is a backdrop of the theme of water scarcity reviewing its historical considerations since the 1992 Earth Summit in Rio de Janeiro, Brazil to the World Summit on Sustainable Development, 2002 in Johannesburg, South Africa and the recent Rio+20 United Nations Conference on Sustainable Development that took place during June 2012 again in Rio de Janeiro, Brazil quoting principles and agreements reached during and after the conferences.

The second chapter on managing water scarcity in Southern Africa looks at the Southern Africa region's efforts to combat water scarcity including principles, policies and strategies put in place to guide the Member States in overcoming challenges arising from water scarcity. Each member state was tasked with the responsibility of implementing these principles. Namibia, in her quest to meet this responsibility, has forged ahead with various undertakings to ensure management of the scarce resource. Over and above instituting water law and regulations pertaining to water management and pollution control and raising awareness of the general public, Namibia encourages relevant research to ensure the attainment of the requirements of both the SADC Protocol and her own national legal instruments governing water scarcity management. The case studies included in this book shed light on how Namibia is addressing some relevant water pollution issues that could reduce the availability of potable water.

The third chapter is a case study on Calueque-Oshakati canal in north-central Namibia. It examines trends and impacts of pollution on water treatment. It presents the results of a study carried out to assess the trends of pollution in the canal and the impacts of pollution on the water treatment processes at four water treatment plants abstracting raw water from the canal. The parameters studied include turbidity, pH, hardness, sodium, total dissolved solids, total nitrogen and *E. coli*. The effect of turbidity and pH on water treatment chemical requirements was also investigated.

The fourth chapter presents research findings of a study on monitoring the effects of anthropogenic activities on water quality of Von Bach Dam in central Namibia. The study examined effects of human activities on the quality of water flowing into Von Bach Dam, the water in the dam as well as water flowing out of the dam during different seasons. The study involved bacteriological testing, turbidity determination and temperature variation within the water body as well as dissolved oxygen content and pH levels.

The fifth chapter on the effects of water transfers from Swakoppoort and Omatako Dams on the water quality of Von Bach Dam presents the outcome of research on the effects of water transferred from two storage dams to augment water quantity in the supply dam. The transfers are made to combat water scarcity in the area by boosting water required for domestic and industrial water supply in central Namibia including Windhoek, Namibia's capital city. Globally, the relevant literature and relevant models for the analysis and prediction of effects of inter-basin water transfers on water quality are reviewed and used in the analysis of the research findings.

The sixth and final chapter contains summaries of the issues discussed in the preceding chapters highlighting drawn conclusions and recommendations put forward in each chapter. A few additional examples from within the Southern Africa region are commented on to further strengthen raised issues including inter-basin water transfer; dam construction; groundwater recharge; rain water harvesting; water recycling and water reuse as well as economical irrigation methods such as drip irrigation.

Josephine Phillip Msangi

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Chapter 1
General Introduction

J. P. Msangi

Abstract This chapter introduces the theme of water scarcity reviewing the historical attention it has received since the 1992 Earth Summit in Rio de Janeiro, Brazil up to the World Summit on Sustainable Development, 2002 in Johannesburg, South Africa and to the recent Rio+20 United Nations Conference on Sustainable Development which took place again in Rio de Janeiro, Brazil. The chapter argues that water scarcity should be distinguished from aridity because water scarcity describes the situation where the available water quantities are inadequate to meet normal activities even in areas outside deserts and other arid areas. Water scarcity can be caused by mismanagement of available water so that it is not available to users; mismanagement that ruins potable water so that it is unusable. While aridity cannot be reversed, water scarcity can be reversed through manipulation to improve water potability through wise usage, budgeting and efficient management of the available water, management that increases access and prevents pollution or excessive losses through evaporation. The analysis quotes and highlights principles and agreements reached during and after the conferences globally and regionally in the Southern Africa Development Community (SADC).

Keywords Water scarcity · Safeguarding water potability · Inequality in access to water and sanitation · Sustainability and principles for good governance · Cooperation and smart partnerships in water management

There is still enough water for all of us – but only so long as we keep it clean, use it more wisely, and share it fairly
(Ban Ki-moon, UN Secretary General 2012)

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Water scarcity has been defined as the point at which the cumulated impact of all users encroach on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Water scarcity is a relative concept and can occur at any level of supply or demand. Scarcity may be a product of society's set-up and interactions among its members and organs (a product of affluence, expectations and customary behavior) or the consequence of altered supply patterns (stemming from changed climatic conditions for example). Hydrologists typically assess scarcity by looking at the population-water equation. An area is experiencing water stress when annual water supplies drop below 1,700 m^3 per person. When annual water supplies drop below 1,000 m^3 per person, the population faces water scarcity, and below 500 cubic meters "absolute scarcity" (UN-Water 2006).

Rio+20 was held twenty years after the 1992 Earth Summit in Rio de Janeiro, Brazil where countries adopted Agenda 21 widely known as the blueprint guiding world countries to rethink economic growth, advance social equity and ensure environmental protection. During 20–22 June 2012, United Nations Conference on Sustainable Development took place again in Rio de Janeiro, Brazil to deliberate and agree on a range of smart measures that geared towards reducing poverty while promoting decent jobs, clean energy and a more sustainable and fair use of resources. The official discussions at Rio+20 focused on two main themes: how to build a green economy to achieve sustainable development and lift people out of poverty and how to improve international coordinated collaboration for sustainable development. Water was one of the areas that received priority attention at this summit. The key water issues addressed at the summit include:-

Ways of increasing access to water and sanitation: By the time of the conference, 780 million people had no access to an improved drinking water source and 2.5 billion people had no access to improved sanitation.

Integrated Water Resources Management (IWRM): An examination of the extent and status of development and application of IWRM approaches first recommended during the 2002 World Summit on Sustainable Development held in Johannesburg, South Africa.

Water Cooperation: The extent of cooperation and dialogue among all stakeholders in attaining better understanding of the challenges and benefits of collaborative undertakings geared towards addressing sustainable development.

Water in the Green Economy: Assistance to countries by international organizations in shifting from current practice to build green economies in the context of sustainable development and poverty eradication (UN-Water 2012).

Fresh water as found in the atmosphere, on the earth's surface and below the earth's surface support most life forms on the earth, yet fresh water is scarce, most of it being locked up in the ice caps and below the ground out of reach of the human population and other life forms upon which human life systems depend on. Since time immemorial, human civilizations have thrived, shrunken or even disappeared altogether due to availability or lack of fresh water for drinking, cooking, cultivation and/or navigation. Great river systems such as the Nile, Zambezi, and

Orange have and continue to support the lives and economies of many communities and national economies. Likewise, oceans and seas support marine life and provide communication between nations and continents in transporting bulk goods and recreation. Thus it is essential to develop and manage the water resources that are readily available to man and animals as well as plants which supply man with food and other goods essential for life sustenance.

The planet earth has been described as the water planet, yet most of this water is not readily available for use as it is in oceans as salty water (97.5 %). Most of the remaining 2.5 % is stored in a solid state in ice caps in the North and South Pole area or deep down well below the surface as groundwater, leaving less than 1 % easily accessible as freshwater in lakes and rivers. Water is a renewable resource which gets renewed through the hydrological cycle which circulates evaporated water from the earth's surface into the atmosphere and after condensation processes falls back onto the earth's surface as pure fresh water. While the earth cannot run out of fresh water, the quantity is finite. Planet Earth's hydrological system pumps and transfers about 44,000 km^3 of water to the land each year, equivalent to 6,900 m^3 for everyone on the planet. A large part of this flow is accounted for by uncontrollable flood waters or water too remote for effective human use. Even so, the world has far more water than the 1,700 m^3 per person minimum threshold that hydrologists by convention treat as the amount needed to grow food, support industries and maintain the environment (Ross-Larson et al. 2006).

While there is enough water to meet world's demand, the global average is a largely irrelevant number just like the world's wealth (although globally there is more than enough wealth to go round, due to unequal access and uneven distribution, some countries, and even individuals have more than others). Almost a quarter of the world's supply of fresh water is in Lake Baikal in sparsely populated Siberia (Ross-Larso et al. 2006). Differences in availability across and within regions further highlight the distribution problem. With 31 % of global freshwater resources, Latin America has 12 times more water per person than South Asia. Some places, such as Brazil and Canada, get far more water than they can use; others, such as the Middle East and Sahel countries in Africa get much less than they need. And water-stressed regions in China and India are not relieved by Iceland's water availability of more than 300 times the 1,700 m^3 ideal starting quantities per person. Within regions too there is often a large disparity between available water resources and population numbers. As such, water scarcity is gaining the attention of many world organizations and what is emerging is the need for increased integration and cooperation to ensure sustainable, efficient and equitable management of scarce water resources, both at international and local levels.

Water scarcity already affects every continent; Sub-Saharan Africa has the largest number of water-stressed countries of any region. By 2007, around 1.2 billion people, or almost one-fifth of the world's population, lived in areas of physical scarcity, and 500 million people were approaching this situation (UN-Water 2007). By 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions. With the existing climate change scenario, almost half the world's population will be living in areas of high water stress by 2030, including between 75 and 250 million people in Africa. In addition, water scarcity in some arid and semi-arid places will displace between 24 and 700 million people (UN-Water 2007).

Water scarcity is defined as the point at which the aggregate impact of all users encroach on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully. Water scarcity is a relative concept and can occur at any level of supply or demand. Water scarcity is a complicated issue which can be understood if one considers not just naturally available quantities but also economic, social and institutional as well as infrastructural development. Scarcity fluctuates over time and space; it is a function of supply and demand both sides of the equation being shaped by social set up, political choices and public policies of any given country. For example sub-saharan Africa as a region has plenty water, uneven distribution places a country like the Democratic Republic of Congo well above others. It has about 25 % of the region's water so that her citizens could enjoy 20,000 m^3 if there was equal distribution in all areas of the country (UN-Water 2007). But there too, like in Namibia and South Africa's Namib and Kalahari deserts as well as other remote rural areas some localities enjoy much less than those in better supplied neighborhoods. Therefore the social organization and infrastructure has a great role to play in alleviating water scarcity.

Worldwide, water demand to meet the various uses has been growing much faster than population for the last several decades and that trend is documented to be continuing. Over the past hundred years population quadrupled, while water use grew by a factor of seven. As the world got wealthier, it also became thirstier (Ross-Larson et al. 2006). Water use patterns have also changed. At the beginning of the twentieth century industrial water use far surpassed other uses but during the twentieth and twenty-first centuries agriculture overtook all other uses so that agriculture still takes the lion share. In developing countries agriculture still accounts for more than 80 % of water consumption due to the fact that population has rapidly grown to require fast food production which has called for increased usage of water for crop growing and processing of agricultural produce. While people have a minimum requirement of 20–50 liters per day, agriculture requires 3,500 liters of water to produce enough food for a daily minimum of 3,000 calories (Ross-Larson et al. 2006).

Water demand is projected to accelerate with the projected population growth and growth in urbanization and industrialization. It is projected that the world population will reach 8 billion by 2025 and water demand will definitely increase as well placing the world's water resources under acute stress which might occasion further unequal access by those without voice and financial power. Populations whose livelihoods depend on irrigated agriculture and those without means to improve water infrastructure will suffer the most. Sustainability will be in jeopardy; ecosystems that sustain flows of water and ultimately human life will be thrown into disarray.

Sustainability, which has been described as using and managing today's resources without compromising the needs of future generations should include those practices which avoid detrimental actions such as:-

(i) Pollution resulting from dumping untreated waste into fresh water bodies including rivers, lakes and groundwater aquifers; over use through over-pumping ground water from identified aquifers and
(ii) Over-use of surface water sources where usage far exceeds available supply including abstraction rates that far surpass recharge rates. The world wide problem of uncontrolled population growth which has led to population explosion in some regions has led to demands that far exceed available fresh water quantities.

Thus, sustainability in managing water resources calls for wise usage, conserving quantity as well as quality and protecting water sources through sound land use practises. Practices that avoid causing irreversible damage to water quality and other resources linked to it such as soil and ecosystems. These practices should also include those geared towards additions to the readily available quantities through deliberate interventions such as harvesting and storing rainwater, water reuse, and waste water treatment. Desalination, although classified as a very expensive intervention, could be used to treat brackish and saline water to augment readily available fresh water where there are no other cheaper alternatives.

Sustainable practises are expected to enhance long term development of any area and its resources where appropriate technologies are employed to increase quantities available for use through harnessing physically available water as well as curbing pollution through water pollution control and waste water treatment, reuse and recycling. The aim then becomes that of achieving more with what is available through awareness building, education and skills building, change of attitudes, and enacting sound policies at all levels of society. Water resources of an area always face enormous challenges arising from competitive usage due to multiple demands on the resource. One way of managing this competition is planning to do more with given quantity where the same water source can be used to support more activities through careful demand combination to achieve multiple usages and prudent budgets for the available quantity. Enacting and promoting sound conservation policies and practises such as recycling and re-use through treating polluted water before dumping should be included in such policies. Pollution caused by dumping of untreated waste into marine areas threatens the fisheries resources upon which large sectors of the population and the economy relies on.

Some simple water management policies allied to appropriate technology can help to create a balance between water supply and demand. One example is waste water recycling; the use of wastewater by treating sewage so that it can be safely restored to rivers used for irrigation or deployed for industry or may even be incorporated into the urban water supply system under extreme scarcity as is being practiced in some cities including the city of Windhoek in Namibia (Esterhuizen 2005).

Successful direct reclamation as practiced in Windhoek is based on the practice of diverting industrial and other potentially toxic waste water from the main domestic waste water stream. The domestic waste water is treated to produce an effluent of adequate and consistent quality which is further treated to produce safe potable water. In addition, it is ensured that the process continuously maintain a multiple-barrier treatment sequence as a safeguard against pathogens and other potentially harmful and unwanted contaminants. Intensive bio-monitoring programs and other tests are carried out on reclaimed water, and for Windhoek, no negative health effects have been detected as a result of the use of reclaimed water since 1968. In order to ensure successful direct reclamation, the multiple-barrier approach ensures that at least two (in many cases three and more) effective removal processes are in place for each crucial contaminant that could be harmful to human health or aesthetically objectionable (Fig. 1.1; also Appendix 1.1).

Recycling wastewater for agriculture being practiced in urban fringes (peri-urban) is a common practice in several countries. Wastewater is estimated to directly or indirectly irrigate about 20 million hectares of land globally. It is estimated that about 12,000 hectares of agricultural land are irrigated using waste water in Kumas, Ghana where dry season irrigation with wastewater raises average agricultural incomes by 40–50 %, with the predictability of supply and the high nutrient content of the wastewater enabling farmers to enter higher value-added vegetable markets (Scott et al. 2004). Expanding capacity for wastewater recycling, by increasing the supply and productivity of water, could generate multiple benefits for poor and vulnerable agricultural producers.

Wastewater can also be used to replenish aquifers, thus prolonging their productivity and guard against groundwater depletion. With urban and industrial water use projected to double by 2050, wastewater could prove to be an expanding and dependable supply provided extreme care is exercised in treating waste water before incorporating it into the supply system or before using it to irrigate crops; particularly horticultural produce which is consumed raw. The regulated use of treated water could significantly alleviate the adjustment pressures now facing water management in agriculture. Israel demonstrates the potential. Over two-thirds of the wastewater produced in the country every year is now treated and used for irrigation in agriculture. Most comes through the national water company, which also sets stringent rules for treatment levels: lower quality wastewater is allocated to tolerant crops such as cotton, with higher treatment standards applied to water for irrigating vegetables or replenishing groundwater (BESA 2000). Thus Tel Aviv’s wastewater supports agricultural irrigation in the arid southern region. Other countries are following Israel’s lead; cities in water-scarce parts of California are investing heavily in plants that treat all domestic and industrial waste to a high standard, reusing the water for agriculture and industrial cooling.

Polluted water causes untold damage to the environment and to the populations that utilize untreated water either for household needs; for animal watering, crop growing or food processing. It is widely documented that every year millions of children die from diarrhoea and other diseases caused by dirty water. Meanwhile ill health associated with water deficits and poor quality undermines productivity

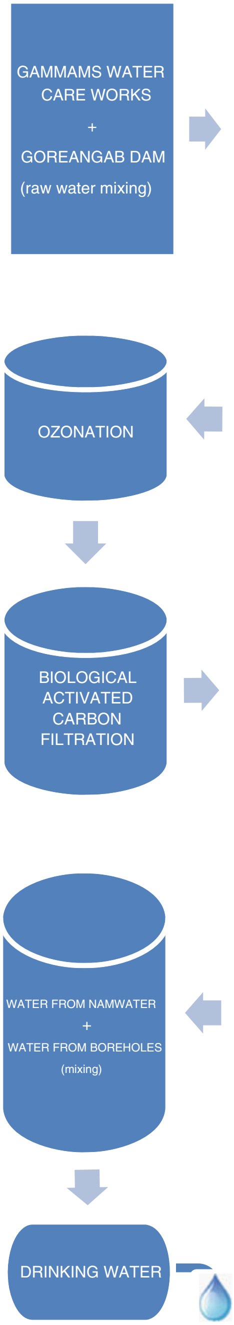

Fig. 1.1 Windhoek water treatment flow diagram (adapted from Esterhuizen 2005) blending different waters for consumption: Goreangab water reclamation plant, Windhoek, Namibia

and economic growth reinforcing the deep inequalities that characterize current patterns of globalization and trapping vulnerable people in cycles of poverty contrary to the requirements of the millennium development goals 1–8 (Appendix 1.2). Similarly, technologies that will reverse the current trend of drying rivers and falling water table will go a long way to ensure that all water demands are met.

Management of water resources to curb scarcity should be looked at in an integrated manner (together with the management of other resources which affect water availability, both quantity, and quality). Land management should form part of water management because clearing land for cultivation or logging for timber and firewood or charcoal production to meet escalating energy demands increases surface runoff and limit infiltration which would in turn reduce recharging groundwater aquifers. Other careless land practices such as wide-spread burning or overgrazing would lead to compaction and hardening of the surface soil producing similar impacts which would reduce availability of ground water. Conversion of indigenous forests to plantations of fast growing tree species such as pine and eucalyptus leads to reduction of surface litter that encourage infiltration and thus reduced dry season flows of many rivers.

Rivers have been diverted and marshes and swamps have been drained or polluted in the quest to generate wealth or create cultivable land without due consideration of such actions on long term flow regulation of river systems. Water scarcity is an outcome of these deeply flawed approaches. Water scarcity is often induced by policy failures; when it comes to water management the world has been indulging in an activity equivalent to a reckless and unsustainable credit-financed spending spree where water use exceeds sustainable levels. Put simply, countries have been using far more water than they have, as defined by the rate of replenishment. This tendency has generated a large water-based ecological debt that will be transferred to future generations. Thus a reverse to this trend is necessary.

At the World Summit on Sustainable Development in 2002, governments embraced Integrated Water Resources Management (IWRM) as the model for the future. This approach emphasizes managing water allocations within the ecological limits of availability, with a premium on the three Es: equity, efficiency, and environmental sustainability. The stated objective of the IWRM was described as the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. The conference established three key principles for good governance:

1. The *ecological principle* for integrating water management around river basins rather than independent institutional users, with land and water governance integrated for environmental reasons.
2. The *institutional principle* for basing resource management on dialogue among all stakeholders through transparent and accountable institutions governed by the principle of subsidiarity i.e., the devolution of authority to the lowest appropriate level, from user groups at the base to local government and river basin bodies.

3. The *economic principle* for making more use of incentives and market-based principles to improve the efficiency of water as an increasingly scarce resource. (World Summit on Sustainable Development Plan of Implementation 2002).

As broad principles, these are sound foundations for any water governance system. The starting point for integrated water resources management is that all water should be treated as a single environmental resource and allocated within a coherent public policy framework among the main groups of water users: agriculture, industry and households. By factoring in sustainability, the concept also recognizes that there are ecological limits to water use and that the environment has to be treated as a user in its own right.

Because water is a flowing resource rather than a static entity, its use in any one place is affected by its use in other places, including other countries. Water is unlike other scarce resources in important respects. It underpins all aspects of human society, from ecology to agriculture to industry; it has no known substitutes. It is fundamental to life and an integral part of the production systems that generate wealth and well-being. Water can be described as the ultimate fugitive resource, traversing borders through rivers, lakes and aquifers. This calls for public policies and international cooperation. Water transfers and water storage that enables sensible water budgeting across seasons and over years so that surpluses occurring during bountiful years can be used to offset deficits occurring in water deficit areas and during dry years or during high demand periods. For example, water transferred from the Kunene River in western Namibia via a pipeline-and-open canal system has gone a long way in alleviating water scarcity characterising the extremely dry area in the north-central part of the country. The same river has been dammed upstream of the water supply intake (in the Angolan side of the border) to generate much needed power for the urban centres, industries and other institutions in north-central Namibia. This water system is threatened by mismanagement which professes impending water scarcity. Chapter three of this book looks at this water transfer system in greater detail (Figs. 1.2 and 1.3).

Other examples of inter-basin water cooperation and water transfers in Southern Africa are discussed in chapter two of this book.

Therefore continuous planning and management should be practised instead of waiting for critical times such as during drought when deficits prompt ad hoc interventions. Inclusive water partnerships should be sort and jealously guarded. Much of what is perceived as "national water" is actually shared water so that excessive extraction by individual users can lead to past a point of sustainability. This includes overusing groundwater resources as well because over extraction of groundwater on one side of a border, aquifer level falls on the other side badly affecting the source of water for all neighbors dependent on that source as is the case in the Gaza Strip and Lake Chad. International water basins including lakes and shallow groundwater, shared by more than one country cover almost half of Earth's land surface. Two in every five people in the world today live in these basins, which also account for 60 % of global river flows (Ross-Larson et al. 2006).

Fig. 1.2 Calueque dam and part of the Ruakana-Oshakati pipeline

Fig. 1.3 Calueque-Oshakati canal in north-central Namibia

Inclusive smart partnerships should not only include formal governmental agreements but should include civil society participation at all relevant levels. This would create room for inclusion of indigenous knowledge in the management of water resources as well as land management which directly affects water resources management. Many indigenous technologies and practises which have existed for generations should be studied and promoted even if it is with the input of scientifically tested inputs. The civil society, the users and managers at the grass root levels, are as essential to sustainable water management as are scientists with “advanced” skills. Equally, the potential for cross boundary tensions and conflict should not be ignored. While most countries have institutional mechanisms for allocating water and resolving conflict within countries, cross-border institutional mechanisms are far weaker.

Strong institutional set ups are necessary for success. The interaction of water scarcity and weak institutions could be cause for disagreements and possible ecological disasters. The Aral Sea which is described as the world’s worst human-caused ecological disaster resulting from uncoordinated over-use by riparian states is a case in point. Less widely appreciated is the damage caused to shared river systems and lakes by overuse: successful cooperation in the management of shared waters can produce benefits for human development at many levels. Apart from reducing the potential for conflict and ecological disasters, cooperation can unlock benefits by improving the quality of shared water, generating prosperity and more secure livelihoods and creating an avenue for wider cooperation. In Southern Africa for example, one of joint infrastructure programs is generating revenue for Lesotho and improved water supply for South Africa.

Southern Africa (synonymous with SADC) provides a striking example of regional cooperation. Water is a major area of cooperation and integration in SADC. During the apartheid era in South Africa few countries in the region were willing to cooperate with South Africa. Since the end of apartheid shared water management has been on an integral part of regional cooperation, with political leaders playing an important role in defining new rules and developing new institutions. The high level of cooperation reflects the fact that all countries in the region stand to gain together or lose together. Taking a cue from this initiative, the African Union adopted the Sirte Declaration in February 2005, encouraging Member States to enter into appropriate regional protocols to promote integrated water management and sustainable development of agriculture in Africa.

Southern Africa has 15 major international rivers that cut through political boundaries such as the Orange—Sengu River Basin which is the largest river basin in Africa south of the Zambezi River Basin (Earle et al. 2005; Appendix 1.3). In the decade since the end of apartheid in South Africa, water has played a major role in the strengthening of regional integration. The process of forming basin partnerships was triggered by an operational requirement to augment water supply to the economic heartland of South Africa. Since then, however, basin cooperation has been consolidated by improved political relations among the basin states in the following areas:-

1. Legislative innovation: The SADC protocol signed in August 1995 drew on the Helsinki Rules, which had a strong focus on state sovereignty. When both Mozambique and South Africa signed the 1997 UN Convention for the Non-Navigable Use of Shared Watercourses, Mozambique pushed for further revisions. A revised protocol, signed in 2000, gave greater influence to downstream states and to environmental needs. It also established formal procedures for notification, negotiation and conflict resolution. The stronger protocol also had a basis in national legislation. The South African Water Act of 1998 states that one of its purposes is to meet international obligations in regional water management; hence South Africa's credibility in the process was enhanced.
2. Strengthening the institutional framework: The objective of the revised protocol was to promote the SADC agenda of regional integration and poverty alleviation. The member states adopted watercourse agreements and institutions, encouraging coordination and harmonization of legislation and policies and promoting research and information exchange. Several programs were initiated towards these aims such as professional training in integrated water resources management, joint work on data collection and changes since 2001 to centralize management.
3. Regional strategic action plan: A 2005–2010 regional strategic action plan for water management focusing on water resource development through monitoring and data collection, infrastructure development (to increase energy and food security as well as water supply schemes to small border towns and villages), capacity building (to strengthen river basin organizations) and water governance. Each area has its own projects, involving SADC national committees, a technical committee, river basin organizations and implementing agencies.
4. Several challenges that plague these efforts include seasonal variations which continue to put competitive pressure on water availability. Difficulties in implementing the progressive national laws and uncertainties about conflict resolution procedures are visibly high.

Elsewhere in the African continent, there are other notable cooperative examples such as the Nile basin initiative. However, it is reported that progress in the Nile basin has been hampered by inherent inequality in water resource access within the states sharing the basin waters due to old colonial agreements and limited mandates, weak institutional capacity and under financing. These are all areas which require negotiation and patience because international agreements take time to be negotiated and agreed upon; they require well formulated policies to govern water use and safe guard water quality as well as sound financing.

Financing cooperative ventures is an issue that affects regional water development collaboration. This is one area where international support has made a great deal of difference in achieving regional endeavors. The Global Environment Facility (GEF) has taken the lead in assisting legal and institutional reform in water management. On international waters, one of six focal areas, the GEF sees itself as a facilitator for ecosystem-based action programs for trans-boundary water bodies. Their growing importance can be gauged by the various roles in promoting cooperation which include:-

1. **Setting priorities and building partnerships:** In each international basin the GEF supports a multi-country fact-finding process to prepare a trans-boundary diagnostic analysis as the basis for a strategic action program, adopted at a high level and implemented over several years. The process has several benefits: producing scientific knowledge, building trust, analyzing root causes, harmonizing policy, breaking down complex water resource and environmental concerns into manageable problems and promoting water resource management at the regional level. It also draws attention to the links between social, economic, and environmental concerns. For instance, in Lake Victoria (part of the Nile basin) connections were drawn between invasive species, deforestation, biodiversity, navigation, hydropower, migration and disease.
2. **Promoting regional water governance:** Almost two-thirds of GEF projects have helped create or strengthen treaties, legislations and institutions. Since 2000 as many as 10 new regional water treaties have been adopted or are in an advanced stage of development. Perhaps the most successful examples are the International Commission for the Protection of the Danube River and the Black Sea Commission. In 2000 a cyanide spill was reported to the International Alarm Centre for the Danube in time to avert a potentially tragic environmental disaster.
3. **Building national capacity:** A key to ensuring sustainable programs is building the capacity to respond to local demands and concerns. Although there are numerous training workshops, financial constraints impose limits on the participation of local stakeholders. In the Mekong Basin for example, Non-governmental Organizations are active in Thailand but not in Cambodia, Lao PDR or Viet Nam. In Lake Victoria area, poverty and illiteracy are barriers that need to be overcome to attain effective spread of environmental knowledge.

The first step towards effective cooperation for human development is to create a common information pool. Information is necessary for riparian countries to recognize the inefficiencies in unilateral programs that fail to account for interdependencies. It can also help to identify shared interests. Many instances of conflict arise more from mistrust and poor information about the use and abuse of water resources than from substantive differences. Joint research and information exchanges can provide timely notification of infrastructure initiatives, identification of shared interests and development potential, increased chances of reaching agreements and, most important, the foundations of long-term trust.

Since 1991 the GEF has supported fact-finding missions in more than 30 trans-boundary basins, achieving successes to varying degrees in the Aral Sea, Lake Victoria, Lake Tanganyika, the Danube (including the Black Sea) and the Mekong basins. Alongside the GEF, the Global International Waters Program identified 66 sub-regions for evaluating the causes and effects of environmental problems in trans-boundary water bodies. It has also been appreciated that it is important that fact-finding studies go beyond the technical aspects. Community based data collection and survey activities are one vehicle for identifying human development problems. River basin communities possess viable coping strategies; they derive direct benefits from shared water resources and are directly in the line of risks. They are thus an important source of information on environmental hazards and livelihood impacts. Here, too, aid can help build institutional capacity.

The second requirement for successful cooperation is long-term political engagement. Negotiations over shared waters are invariably lengthy, requiring support from donors over relatively long time. There is also scope for working towards regional legislation. The absence of harmonized or structured water policies in riparian countries can undermine efforts at integrated water management across borders. However, harmonization of legislation on water is technically challenging and often politically difficult. Given its experience in the area, the United Nations Environment Program could take the lead in assessing national legislative frameworks and identifying overlaps. These could become the basis for developing regional water policies, as happened in SADC. Donors should aim to substantially increase aid for trans-boundary waters but in the interests of ownership the riparian countries have to bear a substantial part of the financial burden for managing trans-boundary institutions and approaches.

The future lies in facing the water scarcity and management collectively as well as individually as regions; because individual regions are faced with very different challenges when it comes to water management. Broadly, eight themes can be identified:-

(i) Developing integrated water resources management strategies that set national/regional water use levels within the limits of ecological sustainability and provide a coherent planning framework for all water resources.
(ii) Putting equity and the interests of the poor at the centre of integrated water resources management taking into consideration gender inequalities.
(iii) Making water management an integral part of national poverty reduction strategies.
(iv) Recognizing the real value of water through appropriate pricing policies, revised national accounting procedures, and the withdrawal of perverse subsidies encouraging overuse.
(v) Increasing pro-poor water supply through the provision of safe wastewater for productive use by separating industrial and domestic waste and working with farmers to reduce health risks.
(vi) Increasing national investment and international aid for investment in water infrastructure, including storage and flood control.
(vii) Recalibrating the response to global warming by placing greater emphasis on strategies for adaptation in national water management policies and aid efforts.
(viii) Tripling aid to agriculture.
(ix) Multilateral action to mitigate climatic change by reducing carbon emissions.

Climatic factors including global warming which dictate the amount of precipitation and the melting of ice caps greatly influence sustainability in the management of water resources and water dependent ecosystems. Widespread climatic change has the potential to reverse human development gains achieved over generations. Adaptation strategies are called for to enable populations affected live with changed climatic characteristics. Climate variability and uneven water resource distribution calls for policies that promote and support water harvesting and sharing of the resource across ecological regions as well as across political boundaries. Various research scientists and politicians have pointed out that there is high probability that climate change will lead to reduced water availability and greatly reduced food production in sub-Saharan countries (those in Southern Africa included) as rainfall declines and temperature rises. Hunger and poverty will accelerate to unknown levels. Thus major adjustments to water policies are required supported by transfer of clean technologies and adaptations to climate change because climate change is not a future occurrence, rather a reality to which people have to adapt. Adaptation strategies must include effective strategies for rain-fed agriculture on which the livelihoods of millions of people depend on.

Earlier embraced technologies that addressed alleviation of water scarcity included water storage infrastructure that has contributed greatly towards water resources management. However, storage infrastructure has been associated with numerous negative environmental as well as social impacts. An estimated 40–80 million people have been displaced over the years by hurriedly designed dam projects that did not take into account the dislodgement of people and subsequent compensation for the loss of their belongings. Documented in various reports including those by the World Commission on Dams (WCD), such undertakings were characterized by inadequate preparations of new resettling areas causing countless problems which have made this technology unpopular among environmentalists and human welfare organizations (WCD 2000).

In the anxiety to produce cheap hydro-electric power or to supply irrigation water, planners and governments failed to take fully cognizance of the rights and claims of communities lacking bargaining power, with indigenous people often among the worst affected (WCD 2000). In addition, many dams have caused immense social and ecological damage such as siltation, environmental health deterioration and deforestation (upstream effects) as well as reduced fish stocks, damaged wetlands due to lower water sediment and nutrient flows (downstream). In some cases the economic benefits have been exaggerated or not properly computed so that they overshadow the negative impacts (Kaduma 1978; Msangi 1990).

The World Commission on Dams found a systematic bias towards underestimating the capital costs of dams (by an average of 47 %) and overestimating the economic returns to large-scale irrigation. Therefore large infrastructure programs should be subjected to thorough impact studies for their impacts on the environment and to the vulnerable people in particular. That notwithstanding, the benefits of large infrastructures are many and should not be over shadowed by the negative impacts. In many countries such infrastructure provides water for irrigation, reducing the variability of water flows to producers and stabilizing water supplies and minimizing risks associated with inadequate or unreliable rainfall regime. Large water infrastructures also offer important source of renewable energy; for example, it provides about 22 % of electricity generation in Sub-Saharan Africa.

While the contribution of large-scale infrastructure to irrigation and power generation should not be understated, neither should the potential contribution of small-scale infrastructure. Small-scale water harvesting has the potential to store water efficiently, thereby reducing risks as well as to store water close to where it is needed. For example the large volume of water stored in Zambia's Kariba Dam does not help small farmers in drought prone parts of the country. Smaller storage facilities close to the farming land and settlements should have been considered at the time of constructing the large storage (Basilwizi Trust 2009). The appropriate mix of infrastructure is best decided at national and local levels through dialogue between governments and people. The real choice should not be between big and small.

Water harvesting experience shows how community-led initiatives can be scaled up through partnerships. Small reservoirs and rainwater harvesting structures provide an infrastructure framework that, when combined with appropriate land management practices, can increase water availability and reduce water scarcity and inevitable stress for the poor and boost the local efficiency and productivity of water use (Msangi 1995). That framework can enhance water security in rain-fed agricultural areas, bringing food security and the potential for diversification into small-scale market production. Rainwater harvesting is one of the oldest recorded hydrological activities used since 8,000 years ago in the first human settlements in South Asia and 4,000 years ago in Greece and Palestine. Similarly, Southern Africa has a rich history of water harvesting, which ranges from simple village ponds that support a range of local productive and domestic activities today to large impoundments. This is also true across Sub-Saharan Africa where diverse traditional water harvesting practices abound, many involving the direct transfer of rainwater to recharge soil moisture (Msangi 1995).

Appendix 1.1: Windhoek Waste Water Treatment

The famous statement "Africa is the cradle of mankind" applies to Windhoek, the city known as "the cradle of direct potable water reuse". Throughout its existence, Windhoek has had to find innovative ways to ensure that the growth of the City can be sustained. In 1968 the Goreangab Water Reclamation plant was built by the City of Windhoek to reclaim water directly from domestic sewage effluent. Over the years the process was improved and the plant capacity extended to 2.9 mm per annum. Due to the fact that all naturally available water sources in and around Windhoek had been fully harnessed, the New Goreangab Reclamation Plant was constructed and commissioned in 2002. The plant comprises the latest available proven water treatment technology which ensures the total utilization of available effluent from domestic wastewater to guarantee the security of water supply for the future. The new plant has been based on extensive experience (30 years), research done locally, and on input from international experts to assure the compliance to the strictest water quality guidelines applied internationally.

The Windhoek Goreangab Operating Company (Pty) Ltd (WINGOC) and its shareholders are associated with the City of Windhoek in reclamation of potable water from waste water. They produce and supply potable water through total quality management. WINGOC treat the water from Goreangab Dam and sell the water to the City of Windhoek. The removal of waste is done by the City of Windhoek at Gamammas Water Care Treatment Plant. The City's Goreangab Reclamation plant, which started to produce potable water from secondary sewage effluent in 1969, is the pioneer in direct potable water reclamation and currently supplies 25 % of the City's drinking water demand. It has been shown over a period of 43 years that reclamation can indeed be the Blue Resource of the future.

Appendix 1.2: Water Scarcity and the MDGs

The way water scarcity issues are addressed impacts upon the successful achievement of most of the Millennium Development Goals[1]

- **MDG 1**: Access to water for domestic and productive uses (agriculture, industry, and other economic activities) has a direct impact on poverty and food security.
- **MDG 2**: Incidence of catastrophic but often recurrent events, such as droughts, interrupts educational attainment.
- **MDG 3**: Access to water, in particular in conditions of scarce resources, has important gender related implications, which affects the social and economic capital of women in terms of leadership, earnings and networking opportunities.
- **MDGs 4 and 5**: Equitable, reliable water resources management programmes reduce poor people's vulnerability to shocks, which in turn gives them more secure and fruitful livelihoods to draw upon in caring for their children.
- **MDG 6**: Access to water, and improved water and wastewater management in human settlements, reduce transmission risks of mosquito-borne illnesses, such as malaria and dengue fever.
- **MDG 7**: Adequate treatment of wastewater contributes to less pressure on freshwater resources, helping to protect human and environmental health.
- **MDG 8**: Water scarcity increasingly calls for strengthened international cooperation in the fields of technologies for enhanced water productivity, financing opportunities, and an improved environment to share the benefits of scarce water management.

[1] UN Water International Decade for Action Water for life 2005–2015. Water Scarcity; Water Scarcity and the MDGs www.un.org/waterforlifedecade/scarcity.shtml.

Appendix 1.3: An Example of Successful Trans-boundary Rivers Management in Southern Africa: ORASECOM

The Orange-Senqu River basin is the largest river basin in Africa south of the Zambezi River basin (Earle et al. 2005). This trans-boundary water resource covers large portions of South Africa and Lesotho as well as southern regions of Botswana and Namibia. Urban development over recent decades, and the corresponding development of water infrastructure have made the Orange-Senqu River basin 'the most developed river basin in Southern Africa' (Earle et al. 2005; Jacobs 2009).

The commission was established by the Governments of Botswana, Lesotho, Namibia and South Africa through the "Agreement for the Establishment of the Orange-Senqu Commission" on 3 November 2000 in Windhoek, Namibia (Earle et al. 2005). ORASECOM is the first commission established following the regional ratification of the Revised Protocol on Shared Watercourses in the Southern African Development Community (Revised Protocol) in 2004. ORASECOM promotes the equitable and sustainable development of the resources of the Orange-Senqu River. ORASECOM provides a forum for consultation and coordination between the riparian states to promote integrated water resources management and development within the basin. The goals of ORASECOM are to:-

- Develop a comprehensive perspective of the basin;
- Study the present and planned future uses of the river system; and
- Determine the requirements for flow monitoring and flood management.

The highest body of ORASECOM is the Council, which is supported by various Task Teams ho which manage projects, and by a Secretariat. The Council serves as technical advisor to the he Parties on matters related to development, utilization and conservation of water resources.

The Council comprises delegations from each of the four member states. Each state delegates three representatives, drawn from its agency responsible for water affairs:

- Botswana: Ministry of Minerals, Energy and Water Resources
- Lesotho: Ministry of Natural Resources
- Namibia: Ministry of Agriculture, Water and Forestry
- South Africa: Ministry of Water and Environmental Affairs.

ORASECOM is the only example of a River Basin Organization in SADC that is financially supported solely by the member states. The Orange-Senqu River basin provides an example of a river basin progressing towards cooperative management of trans-boundary water resources in SADC. These efforts are being supported by the development of a basin-wide Integrated Water Resources Management Plan.

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Chapter 2
Managing Water Scarcity in Southern Africa: Policy and Strategies

J. P. Msangi

Abstract This chapter reviews Southern Africa region's efforts to combat water scarcity including enacted water policies, agreements and strategies (such as inter-basin water transfers) put in place to guide the Member States in combating the challenges arising from water scarcity that is affecting a large portion of the region. Unequal distribution and rainfall variability and unreliability compounds an already bad situation because while in other parts of the region there is seasonal water abundance, in other parts there is perpetual deficit. The regional organ (SADC) was formed with the primary objective of integration and cooperation among member countries with water considered as a critical factor to the integrated and cooperative socio-economic development of the region. The coordinated, sustainable and integrated development and management of the region's water resources is expected to contribute to the region's goal of attaining an integrated regional economy built on the basis of balance, equity and mutual benefit for all member states. Water management particularly supports the SADC objectives of poverty reduction, food security, energy security and industrial development, as well as being an instrument to promote peace and cooperation amongst the partners.

Keywords Rainfall variability · Integrated water resource management · Trans-boundary watercourse systems · Inter-basin water transfers · Legal and non legal water instruments · SADC water protocol · SADC regional water policy · SADC regional water strategy

> *Among the many things I learnt as a president, was the centrality of water in the social, political and economic affairs of the country, the continent and the world*
> (Nelson Mandela, World Summit on Sustainable Development, 2002).

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Introduction

Southern Africa is synonymous with Southern Africa Development Community (SADC) which is formed by 15 sovereign states (12 continental states and three island states); they include Angola, Democratic Republic of the Congo, Botswana, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. The regional grouping was formed in 1980 by nine continental member states as the Southern Africa Development Co-ordination Conference (SADCC). It was then transformed into the Southern African Development Community in 1992, seeking to integrate the economies of the region to consolidate regional co-operation and development.

In general, water is a finite and a scarce resource in many parts of Southern Africa region. While in other parts of the region there is seasonal water abundance, in other parts there is perpetual deficit. Rainfall is widespread in the northwest region encompassing the Democratic Republic of Congo (DRC) and scarce in the southwest parts that include Namibia and North Western Cape Province of South Africa. The total annual rainfall ranges from less than 100 mm in the Kalahari and Namib Deserts to over 2000 mm in the north and central tropical regions of Angola and the DRC.

Water scarcity is a recognized norm in a large part of Southern Africa region. The region has very arid conditions in the south-centre and south west of the continent, and is subjected to high climatic variability and highly unreliable rainfall regime which worsens the region's vulnerability to recurring droughts. The region has unevenly distributed water resources (both temporal and spatial). This unevenness extends to both surface and groundwater resources. The bulk of the regional water resources are found in 15 trans-boundary water courses (Appendix 2.1). In 1991–1992 the region experienced one of its debilitating droughts; this experience appears to have been instrumental in speeding up the implementation of regional integration and water resources management strategies (Fig. 2.1).

The continental SADC region covers some 9,271,061 km^2. The average population growth rate is estimated at 3 % and the density is estimated at 21.6 persons per km^2, with just over 30 % of the population in urban areas (SADC 2007). However these figures give a general picture, they need to be adjusted so that they reflect regional disparities and the impact of diseases and rural–urban migration. The region is endowed with an immense and wide variety of natural resources, including minerals, wildlife, forests and fisheries. Collectively, these natural resources form complex ecosystems which support a rich biological diversity which could ensure food security. However water, a key natural resource sustaining the bio-diversity varies significantly in the region, geographically and seasonally. By mid-2000, the region had a population estimate of 240 million people and was expected to double in 25 years; this would definitely create additional demand on the already stressed water situation which, by mid-2000, far exceeded supply. Thus solutions were discussed and proposed and follow ups are

Fig. 2.1 Southern Africa states (Seychelles not shown on the map) *Source* Malzbender, D., & Earle, A. (n.d.). Water resources of the SADC: Demands, dependencies and governance responses

currently being pursued with the help of sympathetic donors as well as by the regional group own established interventions.

The regional organ (SADC) was formed with the primary objective of integration and cooperation among member countries with water considered as a critical factor to the integrated and cooperative socio-economic development of the region. As such, the coordinated, sustainable and integrated development and management of the region's water resources is expected to contribute to the

Fig. 2.2 SADC secretariat headquarters in Gaborone, Botswana. *source* Malzbender, D., & Earle, A. (n.d.). Water resources of the SADC: Demands, dependencies and governance responses

region's goal of attaining an integrated regional economy built on the basis of balance, equity and mutual benefit for all member states. Water management particularly supports the SADC objectives of poverty reduction, food security, energy security and industrial development, as well as being an instrument to promote peace and cooperation amongst the partners (Fig. 2.2).

SADC's water resources are an important component in realizing sustainable economic and social development of the region. Besides meeting the basic needs of water supplies for domestic and industrial requirements, sanitation and waste management for large population as well as sustaining a rich diversity of natural ecosystems, the region's water resources are critical for increasing food security through better management of rain-fed and irrigated agriculture, aquaculture, and livestock production; and improving access and availability of cheap energy through hydropower.

The foregoing facts led to increasing focus on a strategy to develop and manage the region's scarce water resources and in particular the management of trans-boundary watercourse systems. The critical importance of water to regional integration and economic development was recognized and appreciated by all partners so that the SADC Secretariat was charged with the responsibility of coming up with interventions and management mechanisms and in taking a lead in steering the process. Subsequently, the SADC Water Sector was established in August 1996 renamed the SADC Water Division (SADCWD). The vision of the Water Division is to attain sustainable, integrated planning, development, utilization and management of water resources that contribute to the attainment of SADC's overall objectives of an integrated regional economy on the basis of balance, equity and mutual benefit for all Member States.

Interventions

This section of the chapter constitutes a snap shot on water policy and strategies that bear witness to endeavors undertaken towards the management of water scarcity including governance and financial issues which have a bearing on sustainability. Policies and strategies provide the framework and guidance to support the implementation of best management practices and suitable interventions. Since the foundation of SADCC in 1980 (now known as SADC), member states have been concerned with management of water resources and sustainability issues. At the inception of SADC each country signed a legally binding treaty through which all member countries agreed to coordinate, harmonize and rationalize their policies and strategies for sustainable development in all areas.

To address the issue of managing water scarcity, the variability, distribution disparity as well as the trans-boundary natural occurrence, the SADC formulated several interventions to address the issues in a comprehensive manner. Several legal and non legal water instruments that were formulated and ratified by all members include:-

(i) The SADC Protocol on Shared Watercourses which was adopted 1995 and revised 2000 (Appendix 2.2) was framed to set the rules for the joint management of regional water resources. The overall objective of this Protocol is to foster closer cooperation for judicious, sustainable and coordinated management, protection and utilization of shared watercourses and to advance the SADC agenda of regional integration and poverty alleviation. The Protocol is the SADC legal instrument under which bilateral and multilateral agreements between Watercourse States may be developed. It fosters the development of cooperation at the River Basin level and promotes the concept of Integrated Water Resources Management (IWRM). The IWRM is the fundamental approach that has been adopted by SADC recognizing that water is cross-cutting in nature, both across political boundaries and across sectors.

(ii) The SADC Regional Water Policy (RWP) of 2005 was developed to further the implementation of the Protocol and to provide the framework for sustainable, integrated and coordinated development, utilization, protection and control of national and trans-boundary water resources regionally. Furthermore, it provides the context and intent for water resources management, representing the aspirations and interests of member states (Appendix 2.3).

(iii) A Regional Water Strategy (RWS) of 2006 was developed to provide the framework for the implementation of the Protocol and the Policy. It contains guidelines on how to realize the actions, responsibilities as outlined in the Regional Strategic Action Plan on Integrated Water Resources Development and Management (RSAP 1998).
The RSAP defined seven key areas of intervention:

1. Legal and regulatory framework;
2. Institutional strengthening;
3. Linkages with sustainable development policies;
4. Data collection, management and dissemination;
5. Awareness building, education and training;
6. Stakeholder participation;
7. Infrastructure development.

(iv) The Regional Groundwater Management Program (GMP 1998). Recognizing that groundwater constitutes a major source of water for large tracts of land within the Southern Africa region, groundwater is one of the priority areas that were identified as needing great management strategies. The GMP was formulated to create an enabling environment for the joint management of shared aquifers by putting in place a framework and specific tools to enable effective resource management.

To facilitate the Protocol, a river basin approach was adopted by all partner states in the planning, development and management of water resources, particularly in shared watercourses. Five River Basin Organizations have been formed so far and through them, it is envisaged that the intent of the regional water policy will be implemented and result in much desired integrated management of all freshwater resources, including groundwater aquifers within their boundaries. This approach includes a holistic approach in the usage of both surface and ground water resources; the reuse of water; proper pollution management and the provision of environmental requirements.

Whereas the RWP and RWS are non-binding guideline documents (though adhered to by all member states as they reflect policy statements jointly agreed upon by all of them), the SADC Water Protocol is the legally binding instrument. The regional water program is defined in the Regional Strategic Action Plan on Integrated Water Resources Management and Development. First developed in 1998, implemented over 5 years 1999–2004 and reviewed in 2004 and revised in 2005 into a more focused RSAP2. RSAP 2, its strategic objectives are based in its mission and objective which include maintaining and sustaining an enabling environment for regional water resources development and management.

The goals of the strategic plan include providing a framework for sustainable, effective and efficient planning and management of shared watercourses at regional and related national levels. It includes promoting and supporting strategic infrastructure development for regional integration, socio-economic development and poverty alleviation as well as developing, promoting and facilitating best practices regarding effective participation by various individual and institutional stakeholders in water resource development and management, including women, youth and other disadvantaged groups. The goals also include building and strengthening human and institutional capacity for sustainable management of water resources at basin, national and regional level.

The SADC Water Protocol on the other hand is the framework governing trans-boundary water resources management in the SADC region. The SADC Water Protocol does not regulate the specifics of basin management in the respective basins of the region. Instead it is a framework instrument that contains the accepted key elements of international water law and makes it mandatory for trans-boundary water resources management in the SADC; the elements include among others, equitable and reasonable utilization and the obligation to give prior notice of planned developments in any of the shared basins.

The SADC Water Protocol provides for basin-wide agreements to be concluded between riparian states, in which the management of the respective basin is regulated in more specific terms. The establishment of shared watercourse organizations is provided in article 5 (3) of the protocol. These are seen as instruments in the implementation of the SADC Water Protocol. Specific River Basin Agreements are negotiated and concluded by parties in shared watercourse for example ORASECOM, ZAMCOM and OKACOM which were agreed upon to oversee the development and management of the Orange-Sengu, Zambezi and Kunene River basins respectively. They all uphold the Principles and Provisions of the Protocol but contextualize them to specifics of the respective basins.

Additionally, the SADC Water Protocol established the institutional framework i.e. the SADC Water Sector Organs at the regional level for the implementation of the Protocol. The primary mandate of the SADC Water Sector Organs is to monitor the application of the SADC Protocol and to facilitate the harmonization of water law and policies between SADC Member States while the Member States each have the obligation to implement and enforce the Protocol in their respective countries. The Member States' national laws must ensure that obligations stemming from international agreements such as the SADC Protocol or basin-wide water management agreements are being met.

The SADC Regional Water Policy (RWP) highlights various opportunities for water management to achieve the SADC goal and objectives, as well as other recognized international and regional targets such as the Millennium Development Goals, the goals of the African Union on water through its formulated avenues such as NEPAD. The RWP document outlines broad political statements of intent. The policy framework for the RWP is supported by declarations endorsed by Member States including:-

(a) The SADC's vision of a shared future, a future within a regional community;
(b) The Southern African water vision of equity and sustainability in the utilization of its water resources for social and environmental justice, regional integration and economic benefit for present and future generations.

(c) The Protocol on shared watercourses in the region which strives to foster integration and closer cooperation for judicious, sustainable and coordinated management, protection and usage of shared watercourses.
(d) The Dublin Principles of Integrated Water Resources Management (IWRM).

These four declarations together with principles and objectives from the Millennium Development Goals, World Summit on Sustainable Development, NEPAD and multi-lateral agreements between Watercourse States, were combined into twelve policy principles to strengthen the Regional Water Policy:-

(i) Water is an instrument for peace, cooperation and regional integration;
(ii) Effective public consultation and involvement of users;
(iii) Focus on integrated and people-centred planning including fair compensation for affected parties;
(iv) Further development of SADC water resources through the joint planning and construction of storage, in order to rectify historical imbalances and promote water supply for irrigation and poor communities;
(v) Efficient use of water through demand management, conservation and re-use/recycling, and the efficient use of water in agriculture;
(vi) Recognition of the environment as a resource base and a legitimate user of water;
(vii) The protection of the environment through appropriate user charges and the enforcement of "the polluter pays" and "waster pays" principles, taking into account equity and social justice;
(viii) Integration of water supply, sanitation and hygiene education programs;
(ix) Capacity building to ensure that managers of water, waste and sanitation have the requisite knowledge and tools;
(x) Ensuring that waste is safely managed at or as close as possible to the point of generation;
(xi) Preventing the import (and export) of harmful waste across the national and regional boundaries;
(xii) Gender mainstreaming and addressing HIV/AIDS in water resources management.

The IWRM is the common thread that links the elements of the regional policy. IWRM is characterized by methodologies for institutional development, capacity building, stakeholder participation, integrated planning, conflict resolution and environmental management. Guided by the revised SADC Protocol on shared water courses, the Policy encourages SADC member states to exploit opportunities for joint water resources development in shared water courses to amicably prevent and resolve water conflicts and consolidate regional cooperation in accordance with the principles enshrined in the SADC treaty.

The Water Policy emphasizes that water should be developed and managed to provide economic benefits, human dignity and social well-being. In addition to clean drinking water, Member States should seek to provide water for productive activities to alleviate poverty and balanced development. The policy also emphasizes the fact that water is a vital resource for energy in industrial development as well as food security. Hence the policy commits Member States to the protection of human life, common property and the environment against the effects of water-related natural and human-induced disasters. The policy recognizes the role of SADC Secretariat and calls for the creation of an enabling institutional environment that enhances the participation of all stakeholders.

The objective of the SADC water division in the SADC secretariat is to ensure that water in Southern Africa becomes a sustainable resource through coordinated management, protection and equitable use of its shared waters. The division guides the harmonization of national policies and the implementation of activities by all stakeholders recognizing that water is a shared resource that cuts through both physical and political boundaries. The division takes cognizance of the fact that water development and management is not just a regional task but a national one as well involving all stakeholders.

Guided by the signed agreements and declarations, a variety of actions have been undertaken at the regional level as well as at the level of individual Member States and groupings with a shared water source. A range of agreements and regulatory measures and market-based mechanisms have been used. One good examples of these is the permit system being implemented in South Africa where applications for water use in a specific catchment have to be sought beforehand. An application is considered and rated on the beneficial use it makes of the water on the basis of factors such as environmental sustainability, income and jobs generated and ability to contribute to addressing inequality in the country. Likewise, Zimbabwe has a system of Catchment Councils which allocate water use rights in accordance with environmentally defined water use standards. Such systems increasingly rely on the involvement of the water users themselves in managing water supplies (Matros 2009).

Yet another example of measures taken to ensure maintenance of water quality through using market based costs and incentives to curb pollution is that involving the implementation of a water use charge on a large scale where a user, such as a mine or factory discharges polluted water back into the system. The rate charged depends on the types and levels of pollutants the water user is discharging back into the water source. These charges are levied at the local level, with income being used to manage the catchment and improve the state of the environment along the principle of “polluter pays”. These charges then form part of the operating costs of the enterprise concerned and as with any cost there is pressure placed to reduce it. Companies thus invest in water treatment or water re-use technologies to either reduce the volume of return flow they discharge or to clean it to acceptable standards (Matros 2009).

Another good example undertaken in South Africa involves a collaborative water purification project between Anglo Coal’s Kleinkopje and Greenside collieries and Ingwe’s South Witbank Colliery in South Africa. They had to pump out and treat 20,000 m^3 a day to prevent acid mine drainage into the surrounding groundwater. The local municipality of Emalahleni was looking for an additional water supply of roughly that amount. A joint venture called Emalahleni Water

Reclamation Project was formed and over several years developed a treatment process which made the water safe for municipal use. The municipality has now been contracted to buy this treated mine water, by so doing mitigating its potential water scarcity and also providing an income stream for the coal companies (Matros 2009).

Such win–win solutions are needed for sustainable outcomes to be reached. More of these types of innovative solutions to water scarcity through water quality improvement need to be encouraged throughout the region. Communities ought to be involved more in the management of water resources on which they depend. The solutions lie in collaborative partnerships between the private sector, communities, governments as well as other stakeholders including researchers/academicians and Non-governmental organizations. There are adequate legal and regulatory instruments that have been put in place both by the regional organ and the national governments and by-laws by local governments and individual communities to facilitate such undertakings.

Regional cooperation in water resources development and management is envisaged as an enhancement towards peaceful co-existence between Member States and strengthening of regional security as watercourse states are more likely to safeguard common or shared investments which yield mutual benefits to the participating parties. The Protocol on Shared Watercourses is seen as a formalization of the objectives and mechanisms for this cooperation which is being adapted into bi-lateral and multi-lateral agreements between watercourse states. The cooperation is seen as a promoter of an environment of collaboration and trust between countries; it is contributing towards peace in the region.

The SADC Protocol on Shared Watercourses and other Watercourse agreements provide an opportunity to clearly outline effective dispute resolution processes negotiated by Watercourse States before the conflict arises. Where attempts to prevent disputes have failed, the need for effective dispute resolution is recognized. This may involve coordinated planning and joint management, followed by alternative dispute resolution mechanisms (such as negotiation, conciliation and mediation) where there are disputes, escalating to arbitration, and only involving the SADC Tribunal (or other recognized international adjudication bodies) if other approaches are not institutionalized or do not work. The challenges to managing disputes and conflicts largely relate to the challenges outlined above for regional integration and cooperation in promoting trust and peaceful collaboration.

Challenges

Despite the significant progress made so far, there are several strategic challenges that require further work. The water scarcity rampant in some parts of the region and competing developmental requirements between member states may result in disputes and tension over water. Other challenges arise from a variety of facts including the fact that rainfall in the SADC region is highly variable, with the resulting impact on reliability and disaster associated with droughts; the available water resources are unevenly distributed across the region and water availability and demand are not matched.

Yet another challenge emanates from the fact that there is widespread poverty in the region, with many people not having access to adequate water for basic human needs especially domestic and household purposes as well as water for productive use. The low levels of access to safe drinking water and adequate sanitation adversely impact the livelihoods, health and productivity of the poorest and most vulnerable members of society.

Amongst the key problems that make it difficult to provide people with water in the region is the uncoordinated planning of human settlements. A substantial number of the inhabitants live in the rural areas in the semi-arid south and southwest of the region, dominated by ephemeral rivers, which rely on ground water. Relocating the people is often met with resistance and stigma. There is also a general attachment to ancestral land as well as unwillingness to abandon places with graves and significant cultural sites amongst SADC communities. A good case in point involves the Topnaar community perched along the Kuiseb River in the middle of the Namib Desert who face acute water scarcity, yet they resist relocation (Msangi 2008).

The water infrastructure is unevenly developed across the region so that there is unequal allocation of water among sectors with some sectors like the urban areas being better off than rural areas. Inequality is also found within certain sectors such as urban areas where upmarket areas are better catered for than informal settlements. The global scenario is that the water infrastructure is generally inadequate and often not effectively operated and maintained, so it is unable to meet the growing demands for development and services.

More challenges arise from inadequate and inconsistent water resources information management among the individual states so that there are associated problems for cooperation and planning in shared watercourses. Similarly there is wide range of legal, policy and regulatory frameworks within the Member States making it difficult to establish linkages during enforcement at both national and regional levels, posing challenges for consistent implementation of regional initiatives.

Weak linkages between different sectors and weak information flow and inadequate institutional capacity arising from low levels of awareness, education and training hamper comprehensive and integrated development. Limited or lack of appreciation of the finite nature and economic value of water by some sections of the population and limited awareness and/or lack of effective stakeholder participation and involvement in decision making at a local, national and regional levels, particularly women, the youth, the disabled and the poor remain a great challenge to addressing water scarcity issues in the region.

Sometimes historic considerations of sovereignty by member states tend to limit integration both for the development and management of water resources and more broadly for economic integration. Also there is no universally accepted standard formula to estimate the value of water in the region, particular amongst Watercourse States. This makes it difficult for such Watercourse States to engage in negotiation on sharing the resource, since consensus on the value of the resources is difficult to achieve. Lack of appreciation of the economic value of water and largely communal ownership of the resource in rural areas have an adverse impact on the effort and commitment to better allocate and manage the resource for optimal benefits both as an economic and social good.

Striking a balance between economic, social and environmental water resources allocation remains a challenge, due to the perception that efficiency is attained if priority is given to commercial economic uses. Closely related to this challenge are the inherent large inefficiencies of water conveyance and use in all countries in the region. Inefficient water use is not only unsustainable under a situation of water scarcity, but also imposes significant costs on the economies of the region. Thus a challenge to water management sector is to define and put in place measures that will improve water use efficiency across the region.

There is an overall shortage of human as well as financial resources to fully meet the standards laid out in the regional and national water policies and laws which is a constrain in the effective practical implementation and enforcement of protocol and policy laid down by the regional body. While the relevant laws and regulatory mechanisms are in place, responsible institutions are not adequately manned (SADC 2007). This calls for investments in capacity building at the various water management levels including at the formal water management institutions (national governments) as well as within civil society and community levels. This is a long-term challenge which has been recognized and included in the regional Water Policy document.

Appendix 2.1: River Basin Organizations

The International Commission for the Congo-Oubangui-Sangha Basin (CICOS) is a relatively new RBO and was only created in 1999. Member states of CICOS are Cameroon, Central African Republic, Democratic Republic of Congo and the Republic of Congo. The main objective of CICOS is to improve cooperation amongst the member states, through improved communication using the Congo River and its tributaries. In recent years attention has been on large hydropower projects that use the large quantities of water from the Congo River.

Pangani Basin Water Board

The Pangani River Basin is shared by Kenya and Tanzania and covers about 42 000 km^2. The two countries established the Pangani Basin Water Board (PBWB) and the Pangani Basin Water Office (PBWO) in July 1991 to jointly manage the water resources in the basin. The PBWO reports to the PBWB.

The board's task is to advise the basin water officer on all matters concerning the apportionment of water supplies; the determination, diminution or modification of water rights; measures to be taken in case of drought; and priorities to be given to different water uses in the basin.

Permanent Okavango River Basin Water Commission

The three Okavango Basin states Angola, Botswana and Namibia signed an agreement in 1994 that formed the Permanent Okavango River Basin Commission (OKACOM). 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. The three countries recognize the implications that developments upstream of the river can have on the resource downstream. Most of the river is currently undeveloped and is recognized as one of the few "near pristine" rivers in the world.

Inkomati Tripartite Permanent Technical Committee

The Tripartite Permanent Technical Committee (TPTC) is collaboration between three SADC member states namely, South Africa, Mozambique and Swaziland. The cooperation on the joint management of the Inkomati Basin started in 1992, when South Africa and Swaziland signed the Komati Accord. In 2002 Mozambique joined the Accord and TPTC was founded as one of the first RBOs in southern Africa. One of the main objectives of TPTC is to manage the water flow of the Inkomati River and Maputo River, particularly during times of drought and flood.

Lake Tanganyika Authority

Lake Tanganyika is Africa's oldest and deepest lake, and contains almost 17 % of the world's available freshwater. Millions of people depend on the lake for water, food, and transportation. The Lake Tanganyika Authority (LTA) was established in December 2008 by the governments of Burundi, Democratic Republic of Congo, Tanzania, and Zambia. Its management structure includes the Conference of Ministers, the Management Committee and the Secretariat. The LTA promotes regional cooperation required for socio-economic development and sustainable management of the natural resources in the Lake Tanganyika basin. Furthermore, the LTA coordinates the implementation of the Convention on the Sustainable

Management of Lake Tanganyika. The LTA also coordinates and oversees the implementation of the Regional Integrated Management Program which focuses on establishment of sustainable fisheries, catchment management, pollution control, climate change adaptations, and monitoring programs.

Zambezi Water Course Commission

The agreement to establish the Zambezi Watercourse Commission (ZAMCOM) was signed in 2004 by Zambia, Angola, Namibia, Zimbabwe, Botswana, Malawi, Tanzania and Mozambique. Zambia is yet to sign as the country is still consulting its stakeholders. Currently, seven of the eight countries have signed the protocol, but only four out of the seven have ratified it, with Zambia, Malawi, Tanzania and Zimbabwe still outstanding. The Commission will only come into force when six out of eight countries ratify the Agreement. Meanwhile an interim Secretariat has been established and a draft document prepared to guide the process of operation.

Ruvuma Joint Water Commission

The Governments of the Republic of Mozambique and the United Republic of Tanzania have very recently established the Ruvuma Joint Water Commission with the principal objective of ensuring sustainable development and equitable utilization of common water resources of Ruvuma River basin. The Ruvuma River forms the boundary between Mozambique and Tanzania for a length of 650 km from the coast and has a total length of about 760 km. The entire area of Ruvuma River basin is about 152,200 km^2 of which 65.39 % are in Mozambique, 34.30 % are in Tanzania, and 0.31 % is in Malawi (SADC 2008).

In 2010a, b, SADC released guidelines for strengthening river basin organizations, a series of four guidelines designed to assist practitioners in making decision, based on best practices from River Basin Organizations (RBOs) in the region. Guidelines were developed in the following areas:

- Stakeholder Participation;
- Environmental Management;
- Funding and Financing; and
- Establishment and Development.

The goal of the Stakeholder Participation Guideline is to establish a set of procedures that can assist RBOs implement participatory processes. The importance of active stakeholder involvement and the mechanisms for stakeholder involvement within the Regional Indicative Strategic Development Plan (RISDP) and the SADC Regional Water Policy are highlighted within this guideline. Four strategic areas for implementing participatory processes are presented:

(i) participatory framework, (ii) communication and outreach, (iii) stakeholder consultation, and (iv) collaboration with stakeholders. Additional details on these strategic areas are outlined in the box below.

The Stakeholder Participation Guideline outlines four strategic areas for implementing participatory processes:-

- Under participatory framework, the guidelines recommend defining the context of participation, identifying and classifying the stakeholder groups, developing a participatory strategy and creating an enabling environment. The Stakeholder Roadmap, developed within the Orange-Senqu River basin is an example of a strategy for stakeholder involvement.
- The strategic area of communication and outreach discusses the importance of information sharing to ensure that stakeholders are informed on a range of issues. The possible interventions proposed under this area include: sensitizing the broader public; providing in depth analysis of the core issues; providing first hand exposure to the RBO activities through involving the public in activities; reaching out to marginalized groups and younger audiences; and providing updates and specific information on RBO initiatives through a website. The River Awareness Kit (RAK) approach is provided as an example of a tool for communication and outreach within an RBO.
- Stakeholder consultation focuses on the two-way flow of information with stakeholders. The potential interventions presented include: obtaining contextual information through questionnaires and surveys; gathering input on RBO activities through interviews; and gaining inputs on priorities and preferences through focus groups and public consultation sessions. The Basin Wide Forum established by the Okavango Commission is an example of a stakeholder consultation initiative.
- The collaboration with stakeholders' strategic area focuses on how to act on the information provided by the stakeholders. The possible interventions outlined in the guidelines include developing joint plans, formalizing the institutional framework for stakeholder engagement, and developing the capacity of stakeholders. The Komati Joint Operation Form is a mechanism for stakeholder involvement within the Komati River basin.

The Environmental Management Guideline outlines the critical importance of environmental management within SADC, as outlined in the 2000 SADC Protocol on Shared Watercourses and the SADC Regional Water Policy. The Environmental Management Guideline introduces the key principles of environmental management: sustainability, precaution, integration and participation. The guidelines are presented in three strategic areas: (i) environmental policy, (ii) environmental information management systems, and (iii) environmental management programs.

The purpose of the Funding and financing Guideline is to establish a set of procedures that can assist RBOs become financial sustainable. The different types of RBOs and range of mandates are reviewed and examples of financial strategies for different RBOs are presented. The three strategic areas presented in the Funding and Financing Guideline includes the following:-

(i) Financial planning,
(ii) Revenue streams,
(iii) Financial management. Six case studies from RBOs from around the world are reviewed to gain insight into how the guidelines translate into practice.

The goal of the Establishment and Development Guideline is to propose procedures to assist Governments in establishing institutions to manage trans-boundary watercourses. Institutional arrangements provide the foundation to develop human and financial capabilities to ensure sustainable socio-economic development and environmental protection of natural resources.

Appendix 2.2: The Revised Protocol on Shared Water Courses in SADC

Water has played a unifying role in the SADC region, leading to regional cooperation. The Revised Protocol on Shared Watercourses in SADC (Revised Protocol) was the first binding agreement amongst SADC member states, which illustrates the important role water plays within the region. The Original Protocol was drafted in 1995 to be aligned with the Helsinki Rules. It was revised and signed in 2000 and came into force in 2003. The revised Protocol defines a watercourse as “a system of surface waters and ground waters constituting a unity whole normally flowing into a common terminus such as sea, lake or aquifer.” A watercourse state is a state “in whose territory part of the watercourse is situated”.

The Revised Protocol stresses the importance of taking a basin-wide approach to water management rather than emphasizing the principle of territorial sovereignty. It outlines specific objectives, including the improvement of cooperation to promote the sustainable and coordinated management, protection, and utilization of trans-boundary watercourses and promoting the SADC Agenda of Regional Integration and Poverty Alleviation. The Revised Protocol provides the flexibility for countries to enter into specific basin-wide agreements, which is the approach promoted under the Watercourses Convention. The agreement allows for planned measures, such as environmental protection, management of shared watercourses, prevention and mitigation of harmful conditions and emergency situations (ORASECOM 2007).

The revised protocol on shared water courses in SADC provides the context for the RWP and it states that the over-arching goals are designed to be put into practice by the RWS. Important inputs to the RWS are the SADC Vision for Water, Life and Environment and the Regional Framework for action (RFFA). These led to the development of National Framework for Action, i.e. the National IWRM Plans (SADC 2007).

The over-arching strategies within the RWP are:-

- Regional Cooperation in Water Resources Management;
- Water for Development and Poverty Alleviation;
- Water for Environmental Sustainability;
- Security for Water-Related Disasters;
- Water Resources Information and Management;
- Water Resources Development and Management;
- Regional Water Resources Institutional Framework;
- Stakeholder Participation and Capacity Development; and
- Accessing Funding and Resources.

Appendix 2.3: The Regional Water Policy and Strategy

The SADC Regional Water Policy and Strategy (RWPS) is designed to support the implementation of the SADC Protocol on Shared Watercourses as the key legal instrument for promoting regional cooperation regarding water related issues (SADC 2007). As outlined in the RWPS (2007), the implementation of the Protocol should be supported by the following key activities:

- Strengthening the SADC Water Division as the implementing organization responsible for promoting, coordinating and monitoring the Protocol;
- Negotiating bilateral and multilateral agreements between Watercourse States within the framework of the SADC Protocol, which include mechanisms for the peaceful resolution of disputes;
- Strengthening shared watercourse institutions to promote good governance and cooperation between Watercourse States;
- Strengthening the capacity of Member States to implement the Protocol through the harmonization of national laws and policies, national institutional development and training of personnel.

The Regional Water Policy and Strategy is to be implemented through a series of short-term water sector programs via the Regional Strategic Action Plan (RSAP).

RSAP 1 was implemented during the period 1999–2004 (SADC 2005), and had to establish an enabling environment for the integrated management of water resources in the region, so as to support of the achievement of other regional objectives. SADC implemented 31 of the 44 projects (see Table A.1) in the categories of:

- Legislation, Policy and Strategic Planning;
- Capacity Building and Training;
- Awareness Creation, Consultation and Public Participation;

Table A.1 Projects within the regional strategic action program 1 and 2

Cluster name	RSAP 2 Project Ref.	Project title (*project #*) RSAP 1	Project title RSAP 2
Regional water resources planning and management	RWR 1	*15* Expansion of SADC-HYCOS Project	Consolidation and expansion of SADC-HYCOS
		18 Upgrade and modernize water monitoring systems for lake malawi	
		19 Rehabilitation of joint monitoring systems—Angola and Namibia	
	RWR 2	*14* Assessment of surface water resources	Standards assessment of surface water resources
	RWR 3	*6* Groundwater management program in SADC	Groundwater management program in SADC
	RWR 4	*12* Economic accounting of water use	Support of strategic and integrated water resources planning
	RWR 5	*2* Regional guidelines for dam safety legislation and procedures	Dam safety, synchronization and emerging operations
Infrastructure development support	INF 1	*13* Study for expanding private sector participation in water and sanitation services	Regional strategic water infrastructure program
		27 Control and development of Lake Malawi and Shire River	
		28 Study of the navigability of the Zambezi and Shire Rivers	
		29 Stabilization of the course of the Songwe River	
		30 Lower orange river	
	INF 2	*5* Program on water supply and sanitation for SADC region	Implementation of the water supply and sanitation program for SADC

(continued)

Table A.1 (continued)

Cluster name	RSAP 2 Project Ref.	Project title	
		(*project #*) RSAP 1	RSAP 2
Water governance	WG 1	*8* Implementation program for SADC Protocol on shared watercourses	Implementation program for SADC protocol on shared watercourses
		30 Lower orange river	
		31 Integrated basin management plan for the Okavango River	
	WG 2	*4* Consultative forum on water issues	Promotion of public participation in water resource development and management
		20 Awareness-building for decision-makers	
		21 Involving the media in water issues	
		24 Promotion of stakeholder participation in water resources management	
		25 Feasibility study for creating fund to support NGO/CBO participation in water resources management activities	
		26 Program on means to empower women in water issues	
	WG 3	*1* Regional guidelines for review and formulation of national water legislation	Promotion of implementation of regional water policy and strategy
		9 Regional guidelines for water policy and review in member-states	
		10 Develop and implement national water sector strategies	
		11 Establish regional water sector policy and strategy	
Capacity building	CB 1	*22* Human resources development program	Skills training for water policymakers, managers and practitioners
		17 Training in surveying, mapping and geographic information systems	
	CB 2	*23* WATERNET	WATERNET
	CB 3	*7* WSCU capacity building project	Capacity building support to the SADC water division
	CB 4	*3* Capacity building for joint integrated basin management	Strengthening river basin organizations
	CB 5	WARFSA	Regional water research fund
Total no. of projects	15		

- Information Collection, Analysis, Management and Dissemination and Improved National and Trans-boundary River Basin Management, Planning and Co-ordination;
- Infrastructure Investment; and
- Stand alone—special priority areas.

Implementation of RSAP 1 clearly demonstrated that international cooperation is possible in the management of scarce resources. A good example is the revision and ratification of the Protocol on Shared Watercourses (1995–2003) which provides a framework to reach more detailed agreements (such as the Inco-Maputo Agreement). Another good example of international cooperation is the preparation of the Regional Water Policy. RSAP 1 furthermore showed that local communities can be mobilized and can have an impact on water resources planning.

RSAP 2 (2005–2010) The focus of the second phase was on water and development seated in projects and initiatives to be found in four strategic clusters (SADC 2005; 2006):

- Regional Water Resources Management, Planning and Development (assessment, monitoring, planning, operation);
- Infrastructure Development Support (Regional Strategic Water Infrastructure Development Program (RSWIDP); over 140 projects assessed—38 % in bulk water supply, dams, transfers, and hydropower;
- Water Governance (implementation of protocol, stakeholder participation, implementation of policy and strategy); and
- Capacity Building (skills training, academic IWRM training and research, support to WD, strengthening RBOs).

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Chapter 3
Trends and Impacts of Pollution in the Calueque-Oshakati Canal in North-Central Namibia on Water Treatment

M. K. Shuuya and Z. Hoko

Abstract North–Central Namibia region is faced by absolute water scarcity. The Calueque-Oshakati canal conveys potable raw water to the region from the Kunene River in southern Angola. The canal is exposed to pollution due to human activities. The objectives of this study were to assess pollution trends along the canal and to determine its impact on chemical requirements for the four water treatment plants abstracting water from the canal. Water samples from the canal were analyzed for selected parameters and jar tests were carried out at the treatment plants from February to April 2008. An increase in parameter concentration in the canal was observed from upstream to downstream. The most upstream plant had average experimental coagulant and actual chlorine dosages of 20 and 3.5 mg/l respectively compared to 45 and 7.7 mg/l for the most downstream plant. It was concluded that pollution, which increased along the canal increased the chemical requirements for water treatment.

Keywords Calueque-Oshakati canal · Drinking water · Pollution · Water quality · Water treatment

Introduction

This chapter presents the result of a study carried out between February and April 2008 to assess the trends of pollution in the Calueque-Oshakati canal in north-central Namibia and the impacts of pollution on the water treatment processes at

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the four water treatment plants abstracting raw water from the canal. The parameters studied in the canal were turbidity, pH, hardness, sodium, total dissolved solids, total nitrogen and *E. coli*. The effect of turbidity and pH on water treatment chemical requirements was also investigated.

The study area, 1,100 m above sea level, forms part of the Cuvelai Basin, known as the Cuvelai-Etosha Basin composed of four sub-basins: Tsumeb, Cuvelei-Iishana, Niipele-Odila and Olushandja. Angola borders the area to the north and in Namibia it is bordered by the Kunene Region to the west and by the Kavango Region to the east (Fig. 3.1) (Kluge et al. 2008). The drainage system of the Cuvelai-Etosha Basin is characterized by a number of shallow ephemeral water courses covering an area of about 7,000 km^2 which form a massive inland delta funneling towards the Etosha Pan (Barnard 1998). The climate in the basin is semi-arid, with rains falling from November to April. The rainfall is highly variable in both time and space. The average annual precipitation is approximately 300 mm in

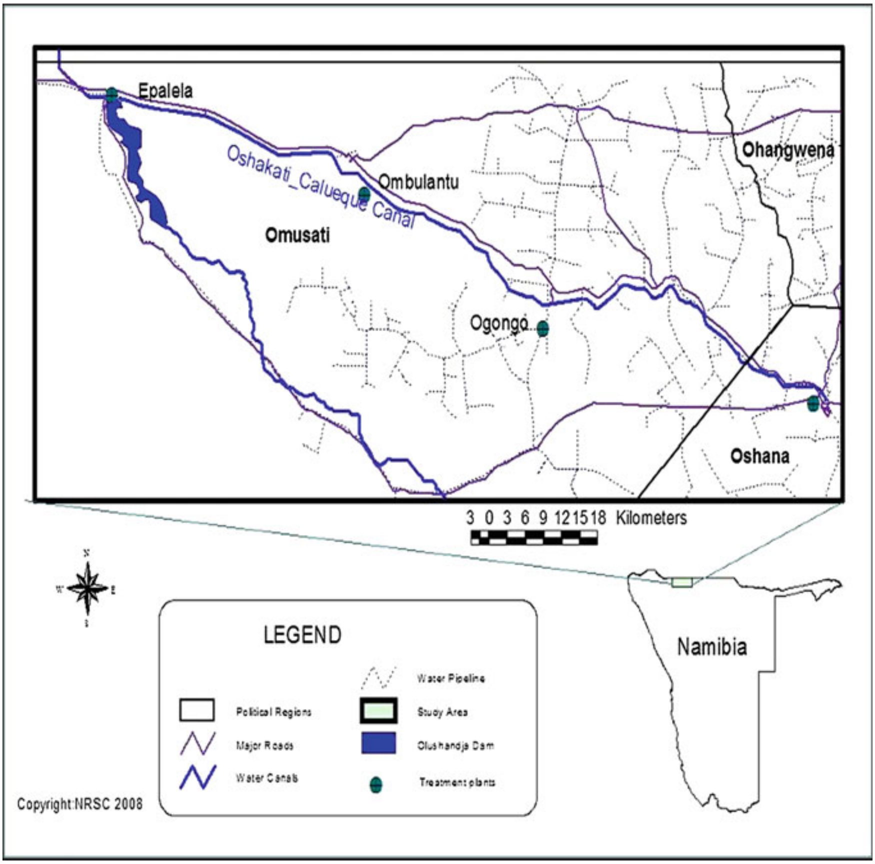

Fig. 3.1 Map of Namibia showing the study area (Map was prepared for the author by Natural Remote Sensing Center of the Namibian Ministry of Agriculture, Water and Forestry)

the southwest and 550 mm in the northeast (Niipele and Klintenberget 2006). Monthly mean temperature ranges from 16 °C in July to 26 °C in November (Hutchinson et al. 1995).

North-central Namibia, like most of the country, is faced with absolute water scarcity. Most of the fresh water used in the area is transferred from Southern Angola via the Calueque-Oshakati pipeline-and-canal which conveys potable raw water to the region from the Kunene River.

Namibia is the most arid country in sub-Sahara Africa; it heavily depends on neighboring countries for its fresh water supply, particularly South Africa and Angola (Kundell 2007). It is only able to provide 360 m^3 per person per year as compared to the minimum of 500 m^3 per person per year suggested by water experts (Heyns 2004). Dating back to the mid-1970s, it became apparent that the semi-arid climate of north-central Namibia coupled with high population growth and density required a new source of fresh water supply as traditional sources could no longer meet water demand and were increasingly susceptible to pollution (Mendelsohn et al. 2002). In line with the Namibia water master plan of 1974, a 154 km long Calueque-Oshakati canal was built to convey water to north-central Namibia from the Calueque Dam on the Kunene River in Angola (Heyns 2004). Four water treatment plants were established along the canal which include Olushandja, Outapi, Ogongo and Oshakati to purify and distribute water to the surrounding villages and urban centers (Mendelsohn et al. 2002).

Until the end of the first decade of the twenty first century, development in the catchment areas of the Kunene River in Angola was still limited largely due to the war that raged in Angola for many years. Consequently the water reaching Namibia was clean and unpolluted; however human influence on the quality of the canal water once it reaches Namibia is increasing at an alarming rate (SOER 2001).

Rapid population growth coupled with growing livestock numbers in north-central Namibia exerted increased pressure on water and soil resources due to dependence on poor subsistence farming that employs poor agricultural practices. Furthermore, the growing livestock numbers and a higher demand for water in the agricultural, commercial and domestic sectors exerted increased water pollution risk due to lack or inadequate wastewater disposal systems, particularly in urban areas (Kluge et al. 2008). The two political regions of Omusati and Oshana through which the canal passes had 83 and 49 % respectively of households with no sanitary facilities in 2001 (Census Office 2002) therefore creating risks of contamination of the canal water by human excreta. People living near the canal are reported to engage in vandalism, swimming and washing in the canal thereby polluting the water (Dragnich et al. 2007). Yet the extent of the pollution of water in the canal has not been studied in great detail. Thus health implications resulting from pollution of the canal water were are unknown. In a study in 2004 by Cinque and colleagues which assessed the health implications of turbidity and suspended particles in protected catchments in Australia, coliform results confirmed how effective protected catchments and good management form barriers to contamination. In 1996 it was confirmed that applied research in Namibia was only carried out when there was need for quick answers (SADC 1996).

The cost of municipal water treatment due to diminished water quality represents an important component of the societal costs of water pollution (Tolman 1997). The costs and difficulty of removing a contaminant by a drinking water treatment plant can be considerable, depending on the material to be removed (KBWSP 2000). Pollution prevention is significantly less expensive compared to remedial measures such as environmental restoration and clean up costs. In 1997, Marquita noted that Americans spent U$ 140 billion a year to control and clean up pollution and in 1996, Maya found out that the deterioration of the raw water quality for the city of Harare resulted in increased chemical dosages for water treatment. Maya reiterated that in 1991 only 35–40 g of aluminum sulphate (alum) treated 1 m^3 of water while in 1992 this figure increased to 75–80 g and in 1995 to 100 g. For a comparison, the Namibian Water Cooperation (NAMWATER) in 2003/2004 spent N$ 52 million (USD 7.4 million) to purify 11,160 834 m^3 of water in the Cuvelai and Kunene areas which are in north-central Namibia (NAMWATER 2008). This translates to 1.5 USD per m^3 which is high compared to the cost of purifying water in South Africa where it is less than USD 0.50 per m^3 and in Europe where it is about USD 0.80 per m^3 (Stephenson 1999).

Thus it becomes clear that pollution of water sources presents financial challenges to developing countries such as Namibia. Poor water quality also produces more sludge during treatment and this call for technical and financial inputs that sometimes exceed that which has been allocated for water treatment (Degrémont 1991). Added costs due to water pollution in the Calueque-Oshakati canal will inevitably push up water costs making it too expensive especially to the 38 % of Namibian households which were classified as poor and 9 % classified as extremely poor (NPC 2008).

The Cuvelai basin is the most densely populated area in Namibia (Census 2002). The 2001 population of 800,000 projected at an annual growth of 2.1 % was approximately 944,700 people in 2008. The region has about half of Namibia's total population (Niipele and Klintenberget 2006). People in the Cuvelai-Etosha basin mainly depend on subsistence agriculture. Pearl millet and sorghum are the most important crops while livestock comprise of cattle, donkeys, goats and poultry. The capacity of the canal starts at 10 m^3/s and decreases in steps along the route to 0.8 m^3/s (NAMWATER 2008). Four potable water treatment plants abstracting raw water from the canal include (from upstream to downstream) Olushandja (WTP1), Ombalantu (WTP2), Ogongo (WTP3) and Oshakati (WTP4). The treatment plants have different capacities (Ombalantu 1584 m^3/day, Ogongo 36000 m^3/day and Oshakati 40000 m^3/day) and all use conventional water treatment processes except for the Olushandja plant.

The Olushandja treatment plant is comprised of two water purification systems, a slow sand filter and a conventional water treatment system with respective capacities of 740 and 1600 m^3/day. The conventional water treatment process includes mixing, coagulation, flocculation, sedimentation, filtration and disinfection. While the slow sand filter plant comprises of sedimentation, mixing, coagulation and flocculation, roughing filters, slow sand filters and disinfection stages.

Study Design

Water quality trends in the canal were studied by assessing the water quality at two sites, one near the Namibia-Angola border and another near the end of the canal in Oshakati. The impact of pollution on water treatment was investigated through considering the corresponding chemical requirements for coagulation and disinfection at the four treatment plants abstracting raw water from the canal. Figure 3.1 shows the locations of the two sampling points on the canal, and the four water treatment plants along the canal. Potential water polluting activities between successive plants are similar in nature and include bathing and solid waste dumping in the canal. Farm and human waste also enter the canal through runoff; however, the risk of sludge from water treatment getting into the canal is minimal. The canal stretch upstream of WTP1 is older and heavily vandalized compared to more recent stretch between WTP3 and WTP4 which was constructed during the last fifteen years and portrayed least malicious damage. The stretch between WTP1 and WPT2 as well as between WTP2 and WTP3 is as old like that upstream WTP1 but portrayed little malicious damage.

Water pollution indicators and parameters considered relevant to water treatment and the quality of the treated water selected included turbidity, pH, sodium, total hardness (TH) as $CaCO_3$, total dissolved solids (TDS), total nitrogen, and *E. Coli*. Turbidity is routinely used to indicate drinking water quality (Mann et al. 2007). Turbidity causes an increase in water treatment costs as it increases coagulant dosages although the relationship is not linear (Pernitsky 2003; Bilotta and Brazier 2008). The location of sampling points and water treatment plants along the canal are shown in Fig. 3.2. It also interferes with the disinfection process and increases sludge generation (O'Neill et al. 1994). The pH was chosen because the coagulation and flocculation, processes necessary for the removal of turbidity and color are extremely pH sensitive (Heinonen and Lopez 2007). Nitrogen is the most prominent element in the Earth's atmosphere and found in many forms in the environment. Sources of nitrogen include; fertilizers applied to agricultural fields, septic fields; wastewater treatment facilities, manure applied to agricultural fields (Alexandria 2004). Nitrogen has negative health impacts especially in infants. Hardness is to some extent linked to taste and also to the ability of soap to form lather in water during bath or laundry (Sawyer et al. 1994). High sodium intake through water has health impacts on humans as it causes hypertension (Bradshaw and Powell 2002). The presence of elevated levels of TDS in drinking water is objectionable to consumers as it may give rise to taste problems, and also results in excessive scaling in water pipes, heaters, boilers and household appliances. *E. coli* provides conclusive evidence of possible fecal pollution and therefore presence health risks to consumers.

Samples were collected in 500 ml water bottles on a bi-weekly basis from February to April 2008. Prior to sampling containers were washed with a detergent and then rinsed using tap water. During sampling the bottles were rinsed three times with the water to be sampled before being filled with the water as recommended by

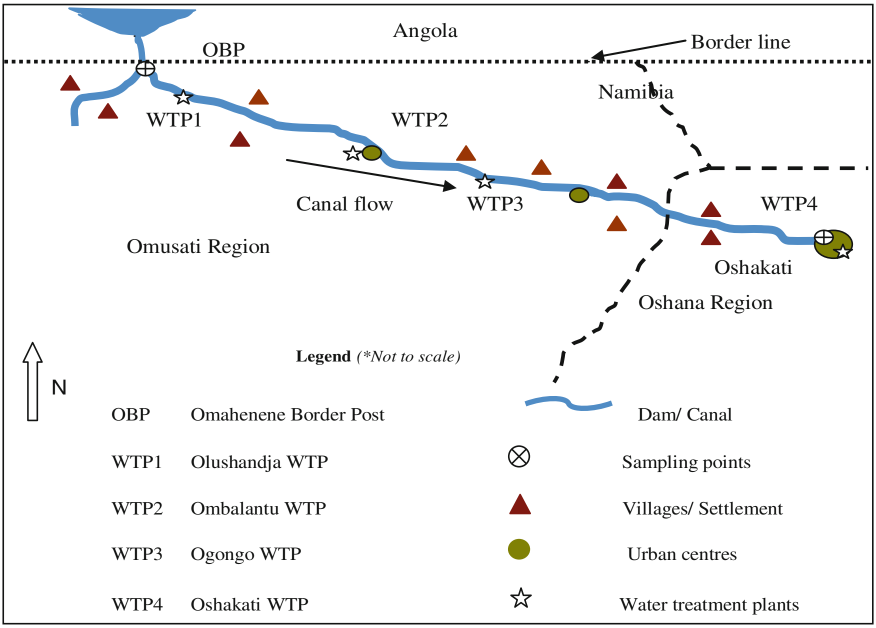

Fig. 3.2 Sampling points near OBP and near OWTP and water treatment plants

Akoto and Adiyiah in their 2007 study report. Samples for microbiological tests where collected in sterile glass bottles. The caps of the bottles were replaced when the bottle was submerged under the water to avoid cross contamination. Sodium, magnesium and calcium (for hardness determination) were analyzed using the Inductively Coupled Plasma (ICP) method. Nitrogen was determined by the use of an automatic colorimetric analyzer. A pH electrode was used to measure pH and the nephelometric method was used to determine turbidity. All the methods used are as described in APHA guidelines 2000. Total hardness as $CaCO_3$ was calculated from calcium and magnesium ion concentrations as suggested by AWWA in their report dated 1990. The enumeration of *Escherichia coli* (*E. coli*) was done in accordance with the standard fermentation technique at the presumptive phase of 24–48 h at temperatures between 37 and 44 °C as recommended by APHA in their report published in 2000.

Jar tests were carried out on water samples collected at the different treatment plants to determine the optimum coagulant dosages. A cationic polymer (Ultrafloc 3200) was used as the coagulant. Ultrafloc 3200 generally used by NAMWATER for coagulation purposes is an aluminum chlorohydrate coagulant that has little or no effect on the water pH. Actual data on coagulant dosage was collected for the period February–April 2008 from NAMWATER records so was the amount of chlorine used to disinfect the water for the respective dates.

Results and Discussion

Water Quality trends in the canal

Water samples collected from the two sites were analyzed for pH, turbidity, total nitrogen, sodium, hardness, TDS and *E-Coli* (Table 3.1).

The increase in levels of pollutants especially nitrogen may give rise to algae growth in the canal which may result in pH increase. Algae and other aquatic plants were observed in the canal during data collection although the levels were not measured. High levels of algae may raise the pH of water bodies (Addy and Green 1996). The high pH is thought to be as a result of photosynthetic uptake of carbon dioxide. The increase in turbidity from upstream to downstream can be attributed to the cumulative effects of runoff and human activities along the canal. Turbidity is due to a variety of suspended matter including colloidal matter (Sawyer et al. 1994). Periods of heavy precipitation, results in high rates of runoff or flood conditions, which cause re-suspension of sediments and increases in turbidity (AWWA 1990). In this case study, surface runoff potentially enters the canal over low-lying areas and at sections where the canal has been vandalized. This study was carried out during a rainy season.

Nitrogen may be linked to agricultural activities in the catchment and pollution by human waste. Livestock farming is an important factor that considerably influences the amount of organic compounds and nitrogen concentration in water ways (Rutkovienė et al. 2005). In this study, traditional systems of subsistence crop production and extensive livestock farming were practiced (Haufiku et al. 2004). Nitrogen is also a component of human excreta (Sawyer et al. 1994), and thus the non-availability of adequate sanitation for part of the population in the basin as reported by Census Office 2002 could be another source of nitrogen pollution for the water in the canal.

The increase in concentration of sodium, and hardness could be attributed to the geology of the study area. It is documented that soils in Namibia vary greatly, with

Table 3.1 Summary of water quality values in the canal for February–April 2008

Stations	pH	Turbidity (NTU)	Total nitrogen as N (mg/l)	Sodium (mg/l)	Total hardness (mg/l)	TDS (mg/l)	*E. coli* (MPN/ 100 ml)
OBP	6.3–7.5 (6.9 ± 0.5)	29–253 (111 ± 86)	6–13 (9.2 ± 3.0)	3–6 (5 ± 1.3)	12–23 (15 ± 5)	38–48 (43 ± 4)	5–10 (4 ± 3)
OWTP	6.4–7.6 (7.2 ± 0.5)	210–284 (243 ± 32)	9–20 (15.4 ± 4.1)	8–21 (14 ± 5)	12–33 (24 ± 9)	41–86 (68 ± 20)	37–45 (42 ± 3)
p^a	value	0.049	0.059	0.002	0.024	0.045	0.053 7.34×10^{-5}

OBP Omahenene Border Post *OWTP* Oshakati Water Treatment Plant
Results are presented as range (mean standard ± deviation) for five sampling campaigns
[a] *P* values are for the *t* test between values for OBP and OWTP

variations at both broad and at local level. The soils in the study area are classified as clayey sodic sands in the lower parts of the landscape and sodic sands on higher grounds (Mendelsohn et al. 2000). The soils in low-lying areas (locally called "Oshanas") have the highest salt content compared to those on higher grounds (Mendelsohn et al. 2002). The high salt content is a direct impact of repeated flooding of the area, which leaves salt behind when the water evaporate. The low-lying areas are spread throughout the regions where the canal is located. When the low-lying areas get flooded the water enters the canal especially in areas where the canal wall has been vandalized or where its clearance above the ground is low. This could be a possible explanation for the increase in hardness and high sodium concentrations as the study was carried out during the rainy period. Ca, Na, Mg, K, HCO_3, SO_4 and Cl, contribute the major part of the mineralization or salts in water (Hoko 2008). The mineralization in water is linked to total dissolved solids (TDS). Ca and Mg are the major constituents of hardness. As a rule, hardness increases with total dissolved solids (Sawyer et al. 1994). Therefore the increase in hardness and Na in the canal is possibly linked to the increase in TDS as a result of ingress of salty water into the canal.

The two regions of Omusati and Oshana through which the canal passes have 83 and 49 % respectively of households having no sanitary facilities (Census 2002). This creates the risk of fecal contamination of the canal water through ingress of storm water especially in the vandalized areas and low-lying portions of the canal. The increase in fecal coliforms can be linked to fecal contamination of the canal through entry of storm water into the canal as well as people swimming and bathing in the canal (Dragnich et al. 2007). There is potential sewage effluent from the waste treatment plants in smaller settlements getting into the canal; however no major spills into the canal were reported during the time of the study. The analysis on the variation in average parameter concentration from upstream to downstream sampling points during the period February to April 2008 show that there is an increase in average values of all parameters from upstream of the canal to downstream. There were significant differences between the values obtained at the two sampling sites ($p < 0.05$) for all parameters except for Turbidity and TDS. The increase in measured parameters from upstream to downstream part of the canal could signal a medium to long term risk of contaminant build up in the canal due to human activities in the basin.

Effect of Pollution on the Water Purification Process

According to the results in Table 3.1, the quantities of total nitrogen, sodium, total hardness and TDS measured are within desirable range for water treatment. As a result the effect of pollution on water treatment was studied by investigating the effects of pH and turbidity on chemical requirements. Samples of water were collected at the abstraction points of each of the four plants. The pH and turbidity of the raw water was also determined for these samples. Jar tests or flocculation tests were then carried out on each of the samples from the intakes of the four

Table 3.2 Summary of experimental raw water pH and turbidity, and optimum coagulant dosages at the four plants obtained from five sampling campaigns in the period February–April 2008

	pH	Turbidity [NTU]	Coagulant dosage [mg/l]
Olushandja	7.7–9.2 (8.1 ± 0.6)	40–228 (129 ± 67)	11–35 (20 ± 9)
Ombalantu	7.7–8.2 (7.9 ± 0.2)	136–249 (181 ± 45)	18–36 (24 ± 7)
Ogongo	7.7–8.1 (7.9 ± 0.2)	164–228 (188 ± 27)	22–35 (29 ± 6)
Oshakati	7.8–8.3 (8.0 ± 0.2)	212–284 (246 ± 29)	35–55 (45 ± 8)

Results are presented as range (average ± standard deviation). Data in this table are based on five data sets corresponding to the number of samples collected during the field work

Table 3.3 Summary of monthly averages of raw water pH and turbidity, coagulant dosages and chlorine dosages from NAMWATER for the four plants for the period February–April 2008

	pH	Turbidity	Coagulant dosage [mg/l]	Chlorine dosage [mg/l]
Olushandja	7.8–9.2 (8.2 ± 0.4)	92–249 (147 ± 45)	15–20 (18 ± 2.4)	1.6–6.2 (3.5 ± 1.0)
Ombalantu	8.0–9.0 (8.4 ± 0.3)	109–231 (171 ± 30)	18–30 (24 ± 3)	1.8–6.2 (3.8 ± 1.4)
Ogongo	7.7–8.1 (7.9 ± 0.2)	150–233 (197 ± 25)	18–30 (24 ± 4)	2.8–6.5 (4.3 ± 1.1)
Oshakati	7.8–8.9 (7.9 ± 0.2)	228–340 (280 ± 40)	24–60 (41 ± 08)	6.1–10 (7.7 ± 1.0)

Results are presented as range (average ± standard deviation). Data in this table is based on average monthly data from NAMWATER records during the period of fieldwork

treatment plants. Ultrafloc 3200 was used for all samples during the tests. Data based on actual records of NAMWATER for the period of study was used to verify and supplement the experimental data collected during the field study. Chlorine dosages presented in this paper are based on actual dosages at each of the plants.

Table 3.2 presents the summary of experimental values of pH, turbidity, and coagulant dosages at the four treatment plants from February to April 2008 while Table 3.3 presents the monthly average values of pH, turbidity and chemical dosages obtained from records maintained at the treatment plants for the corresponding period.

The pH level affects coagulation and disinfection. The average pH values measured during the study and average monthly pH values at the four treatment plants obtained from NAMWATER records are presented in Tables 3.2, 3.3 and Fig. 3.3. A t-test indicated no significant difference between the average monthly actual p values maintained at the plant and the experimental data as in all cases the value of p was greater than 0.05. No significant difference ($p > 0.05$) were found between pH values of successive plants and also between the most upstream and the most downstream plant (i.e. between WTP1 and WTP2; WTP2 and WTP3; WTP3 and WTP4, and between WTP1 and WTP4). However significant differences ($p < 0.05$) in coagulant dosages were found between all pairs of successive plants (except WTP2 and WTP3). For Chlorine significant differences in dosages were found between WTP3 and WTP4 and also between WTP1 and WTP4. This suggests that the raw water pH was not affecting the chemical requirements.

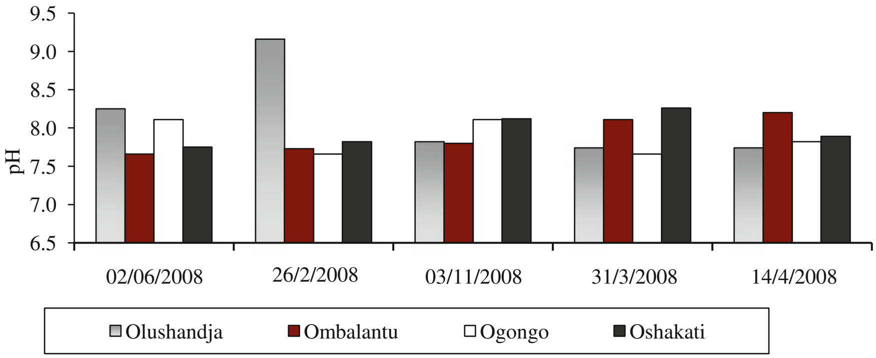

Fig. 3.3 pH values for raw water at the four treatment plants in the period February–April 2008

Water pH is closely linked to biological and chemical processes within a water body and affects water treatment processes (Chapman 1996). The speed and degree of coagulation and flocculation, and the removal of turbidity and colour, is extremely pH sensitive (Heinonen and Lopez 2007). Metal coagulants are acidic, and coagulant addition consumes alkalinity in water. For low alkalinity waters, coagulant addition may consume all of the available alkalinity, depressing the pH to values too low for effective treatment. High alkalinity waters may require high coagulant addition to depress the pH to values favourable for coagulation. The effective pH range for alum coagulation is 5.5–8.0 (John 1977). The canal water pH was within levels preferred for effective coagulation in 95 % of the samples and therefore generally posed no challenges for water purification.

Water pH also affects the rate of disinfection by hypochlorous acid, a species formed when chlorine gas dissolves in water (Sawyer et al. 1994). Chlorine is the primary disinfecting agent in drinking water treatment and is effective at low to moderate pH, however at high pH, chlorine residuals last much longer. According to UNICEF dated 2005, the pH for effective chlorination should be less than 8.5. Chlorine is the main disinfectant used at all the four plants studied. In this study pH was only measured for the raw water. However if pH correction is not done before coagulant application, as is the case generally at the four treatment plants studied, the overall pH of the water during treatment up to the point of disinfection will depend on the pH of the raw water and the coagulant dosage. One of the reported advantages of the coagulant used by NAMWATER (Ultrafloc 3200) is that it has little or no effect on the water pH. Therefore in this case the raw water pH determines the pH for disinfection. In 95 % of the samples the raw water pH was found to be less than 8.5 recommended for effective chlorination (UNICEF 2005).

Therefore the pH of the raw water was generally in a range suitable for effective disinfection. Human activities appear not to be impacting on pH as there was no significant difference between successive plants and also between the most upstream and most downstream sampling points.

The experimental and values obtained from NAMWATER records for turbidity and coagulant doses from all four treatment plant are presented in Tables 3.2 and 3.3. In both tables the average turbidity values show an increase in values from upstream to downstream plants. This confirms the trend of turbidity on canal sampling sites as discussed under the section of water quality trends in the canal. There was no significant difference ($p > 0.05$) between the monthly average experimental values and monthly average values from NAMWATER records for turbidity and coagulant dosages of all the four plants. There were significant variations ($p < 0.05$) for turbidity between WTP1 and WTP2; WTP3 and WTP4; WTP1 and WTP4 and no significant difference between WTP2 and WTP3. Coagulant dosages showed significant variation of mean values ($p < 0.05$) for all successive plants including the most upstream and downstream (WTP1 and WTP4) except WTP2 and WTP3. This suggests that there was progressive impact of human activities on the water quality in terms of turbidity. The trend in variation of turbidity was also the same as that for coagulant dosages suggesting a strong relationship between turbidity and coagulant dosage. Figures 3.4, 3.5, 3.6 and 3.7 show the trends of experimental turbidity and coagulant dosage values at the four treatment plants from February to April 2008. According to NAMWATER employees interviewed at the respective plants, chemical requirements are usually higher in the rainy period (October–May especially the peak period March–April) compared to any other time of the year; this was attributed to elevated turbidity during this period.

The Olushandja plant, which is the most upstream plant, had the lowest average experimental and actual coagulant dosage (20 and 18 mg/l) followed by the Ombalantu plant (24 and 24 mg/l) then the Ogongo plant (29 and 41 mg/l). Oshakati plant had the highest of (45 and 41 mg/l). However, at some of the plants such as the WTP2 (Ombalantu) and WTP4 (Oshakati) the flow meters were not working for some time. WTP1 did not have equipment to determine dosage. This could affect the actual dosages although this was not investigated. Turbidity increased from upstream plants to downstream plants. The increase in turbidity was accompanied by an increase in coagulant dosage. The extent of water treatment for domestic use will depend on the quality of the raw water (Fatoki and Ogunfowokan 2002). High turbidity therefore leads to increased water treatment costs due to increased chemical requirements for water purification (Ribaudo 2000). It can be seen from Figs. 3.4, 3.5, 3.6 and 3.7 that the general trend of turbidity followed that of coagulant dosage. Turbidity increases coagulant dosages although the relationship is not linear Pernitsky (2001). Figure 3.8 shows trends of the experimental and NawWater values for coagulant dosage and turbidity over the study period.

Figure 3.8 demostrates that the coagulant dosage increased with increasing turbidity. There is very little variation between experimental and actual values of turbidity and coagulant. Generally human activities are impacting on water quality along the canal. The increase in the amount of coagulant dosage from upstream to downstream found in this study was related to the increase in turbidity which suggests water quality deterioration along the canal from upstream to downstream

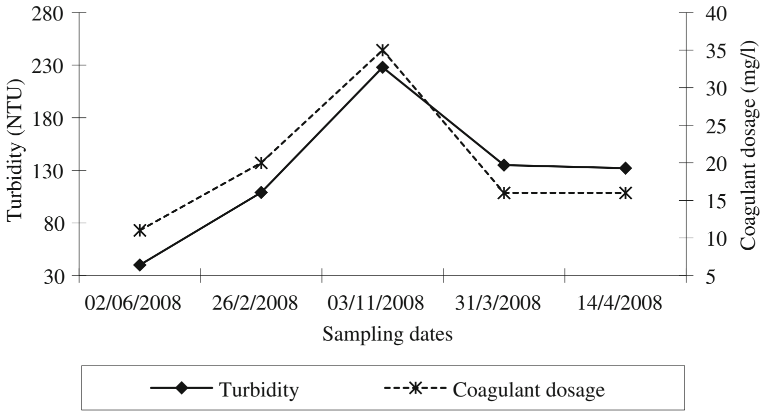

Fig. 3.4 Experimental turbidity and coagulant dosage trends at the Olushandja treatment plant from February to April 2008. (*bold line* on plot-turbidity; *dotted line* on plot-coagulant dose)

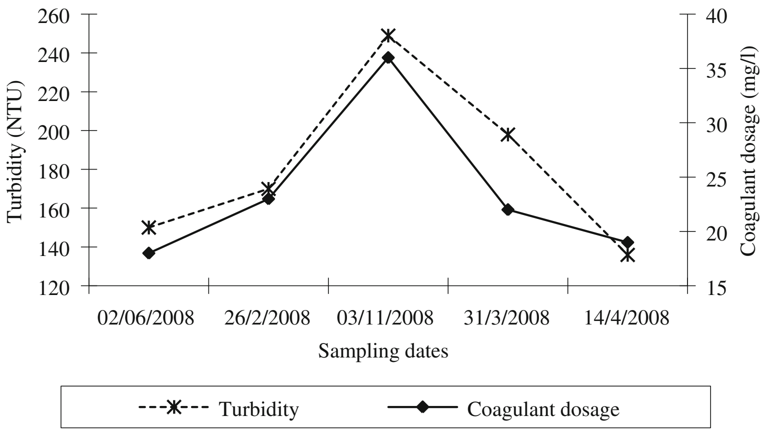

Fig. 3.5 Experimental turbidity and coagulant dosage trends at Ombalantu treatment plant from February to April 2008

impact on water treatment especially the coagulation and flocculation process which in turn affects sedimentation and filtration.

High turbidity also affects the filtration process and increases sludge production (O'Neill et al. 1994). Increase in sludge production also increases cost of water treatment. High turbidity will result in increased need for backwash. The filtration process is the only process operated in a non-continuous manner due to the need to backwash and therefore high turbidity reduces the plant output. Table 3.4 shows the backwashing practices at the four plants in the period of February–April 2008. The frequency of backwashing is dependent on the water quality condition and the amount of solids generated in the coagulation process (EPA 2005).

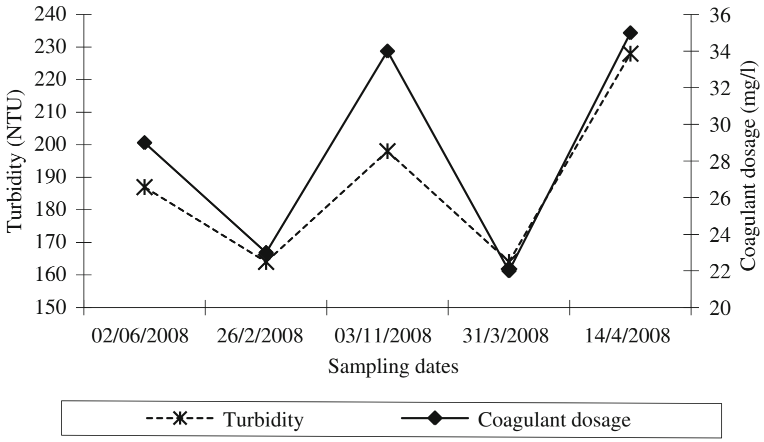

Fig. 3.6 Experimental turbidity and coagulant dosage trends at Ogongo treatment plant from February to April 2008

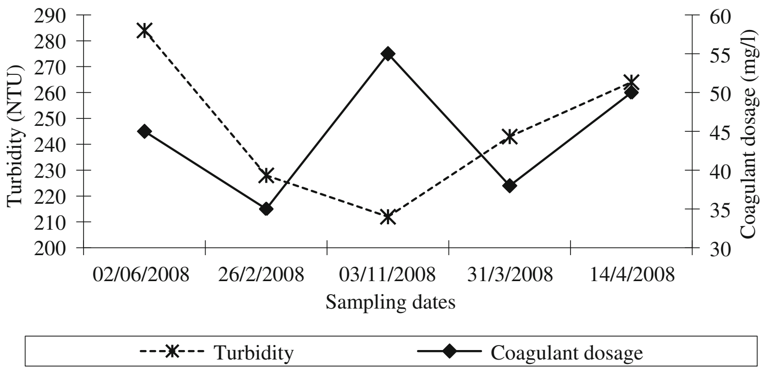

Fig. 3.7 Experimental turbidity and coagulant dosage at the Oshakati treatment plant from February to April 2008

In this study it was found that generally backwashing of filters increased in frequency from upstream plants to downstream ones suggesting that the increase in turbidity from upstream to downstream could be linked to the frequency of backwashing.

The aesthetics of the treated water is affected by the efficiency of the last physical process (filtration) in removing turbidity and this is somehow linked to the turbidity of the raw water. Consumers of public water supplies easily associate turbid water with possible wastewater pollution and the hazards occasioned by it (Sawyer et al. 1994). In conventional water treatment, disinfection normally follows filtration. If the water treatment stages at the four plants have the same efficiency, then the final filtered water quality is related to the quality of the raw

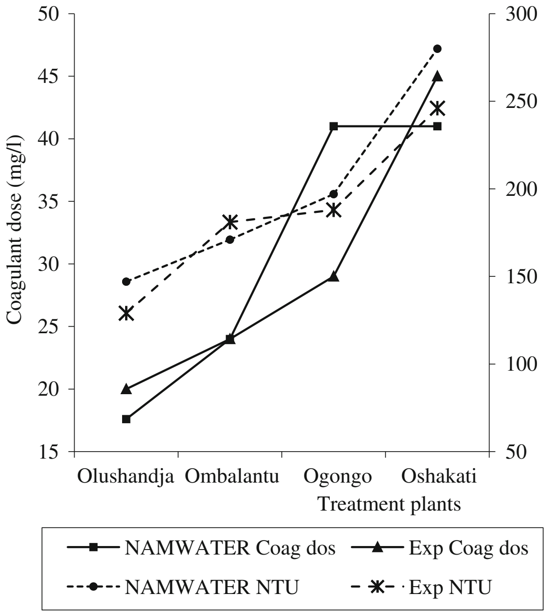

Fig. 3.8 Experimental and NAMWATER values for coagulant dosage and turbidity trends at the four water treatment plants for February–April 2008

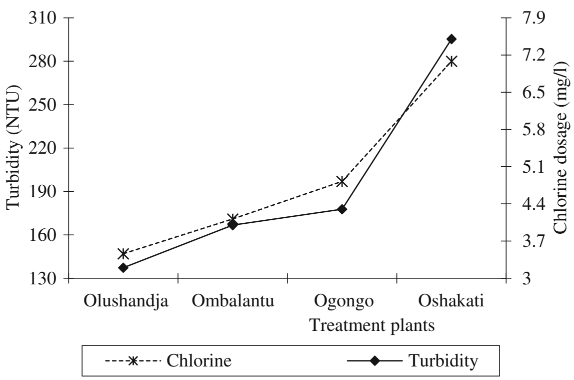

Fig. 3.9 Trends in turbidity and chlorine dosage at the four treatment plants from February to April 2008 based on NAMWATER records

water. In this study the efficiency of different treatment units at the four plants was not studied. Suspended matter in water, which causes turbidity, reduces the microbiocidal efficacy of chlorine and other chemical disinfectants, as the suspended matter shields microbes (Thompson 2003). High levels of turbidity can protect micro-organisms from the effects of disinfection; stimulate the growth of bacteria and give rise to significant chlorine demand (O'Neill et al. 1994). Required chlorine dosage depends on the quality of water (chlorine demand) and the country's drinking water standards—residual chlorine (Solsona 2003). The total amount of chlorine dosed is the sum of chlorine demand and residual chlorine (Degrémont 1991). The summary of actual chlorine dosage (based on NAMWATER records) at the four treatment plants are presented in Table 3.4.

Table 3.4 Details of the backwash process at the four plants in the period February–April 2008

Treatment plant		Backwash frequency	Backwash duration	Backwashing methods
Olushandja	Slow sand plant[a]	once a week	45 min	Water
	Conventional plant	once a week	1 h	Air pressure and water
Ombalantu		2 times a week	3 h	Air pressure and water
Ogongo		3 times a week	20 min	Air pressure and water
Oshakati		once a day	6 min	Air pressure and water

Results in this table are based on NAMWATER records
[a] *For the slow sand filter plant, backwashing is done for the roughing filters which precede the slow sand filters. See* Chap. 2

The Olushandja plant had the lowest average chlorine dosage (3.5 mg/l) followed by Ombalantu (3.8 mg/l) then Ogongo (4.3 mg/l); the Oshakati treatment plant recorded the highest chlorine dosage (7.7 mg/l). As earlier stated, turbidity showed significant differences ($p < 0.05$) between successive pairs of plants except between WTP2 and WTP 3. Chlorine showed significant differences between WTP 3 and WTP4 and also between WTP1 and WTP4. In this study chlorine dosages increased with increasing turbidity levels from upstream plants to downstream plants. It appears therefore that turbidity impacted on chlorine dosage. Figure 3.9 shows trends of chlorine dosage and turbidity at the four treatment plant from February to April 2008 .

The increase in chlorine dosages from upstream to downstream may be linked to the increase in turbidity. It can be concluded that the deterioration in water quality along the canal from upstream to downstream resulted in a corresponding increase in chlorine requirements at the treatment plants.

Conclusions

Three main conclusions can be drawn:-

(1) There was an increasing trend for all parameters studied for the canal from upstream to downstream sampling points along the canal. The increase in concentration was attributed to pollution of the canal as a result of the human activities and runoff in the basin.
(2) The pollution in the canal increased chemical requirements for coagulation and disinfection from upstream to downstream of the canal and also affected the operation of the plants in terms of backwashing as the frequency generally increased from upstream to downstream treatment plants along the canal.

(3) Pollution of the canal water is likely to increase in the medium to long term, especially with more developments in the basin and the corresponding population growth. This will affect the water treatment process significantly resulting in increased water treatment costs and potentially increases in tariffs.

Recommendations

Pollution prevention measures should be taken as a matter of urgency to reduce the amount of pollutants getting into the canal which will consequently reduce the amount of chemicals required for water purification and scarcity of potable water. Measures such as the enforcement of buffer zones for development along the canal, community education and improvement of sanitation in settlements along the canal should be enforced to curb further pollution which will reduce the quantity of potable water and uphold the SADC Water Protocol and its agreed principles.

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Chapter 4
Monitoring the Effects of Anthropogenic Activities on Water Quality: Von Bach Dam, Namibia

J. J. Sirunda and J. P. Msangi

Abstract This chapter is based on research carried out to examine the effects of human activities on the quality of water flowing into Von Bach Dam, the water in the dam as well as water flowing out of the dam during different seasons. The specific objectives of the study were to determine water quality at different points around the Von Bach Dam during different seasons of the year. The study involved bacteriological testing, turbidity determination and temperature variation within the water body. Other tests carried out include dissolved oxygen content and pH levels. Bacteriological analysis showed high presence of *E. coli* which is a strong indication of pollution emanating from human activities. High values for soil and other organic matter were found to be the major contributing factors in raising the dam water turbidity which was responsible for algal blooms in the dam. The pH of the water during summer and winter did not indicate potential harmful effects to human health as these were within the limits of the NAMWATER standards for drinking water.

Keywords Eutrophication · Anthropogenic activities · Inflow and outflow discharge · Turbidity · Coliform bacteria · *E. coli* · Dissolved oxygen · PH levels

Introduction

Namibia is the second driest country in Sub-Sahara Africa and water scarcity is the norm for most of the country. Surface water is almost non-existent with the exception of the five trans-boundary rivers marking its political boundaries with

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Botswana, Angola, Zambia and South Africa. These include Kwando-Linyati-Chobe, Okavango, Kunene, Zambezi and the Orange Rivers. Most of the other rivers are ephemeral carrying water only during and soon after the rains.

Namibia has great temperature variations, the average annual temperature along the coast being less than 16 °C, about 18–20 °C in the central area, 20–22 °C in the south, and more than 22 °C in the northern-eastern parts. However during the hottest months (i.e., October–February), the temperature at the coast remains less than 20 °C, it rises to over 30 °C in the centre, over 36 °C in the southern and over 32 °C in the northern-eastern parts of the country.

In Namibia, annual rainfall varies across the country, where the coastal areas on average receive less than 50 mm per year, the southern part 50–200 mm per year, the central parts 200–400 mm per year and the northern part receives 400–550 mm per year (Mendelsohn et al. 2002). The eastern Caprivi receives the highest average rainfall of about 650 mm per year while some areas in the central part like Tsumeb receive 510 mm per year, Otavi 540 mm per year, and Grootfontein 550 mm per year. Most parts of the country receive rainfall during the summer months (November–March) with the exception of the south–western corner of Namibia which receives winter rainfall during June–August.

The country is characterized by very high evaporation losses (southern areas 2380–2660 mm per year; north-eastern parts 1680–1820 mm per year and less than 1680 mm per year along the coastal area. The highest rates occur during October–January (Mendelsohn et al. 2002).

Overview

This chapter is based on research carried out to examine the effects of human activities on the quality of water flowing into Von Bach Dam, the water in the dam as well as water flowing out of the dam during different seasons. The specific objectives of the study were to determine water quality at different points around the Von Bach Dam including inflow and outflow points at different depths. The study set out to compare quality of water collected at different points in order to determine the effects of human activities on the water quality of the dam. The main research question of the study was to determine the season during when human activities affect the water quality of Von Bach dam the most. Therefore the study involved bacteriological testing, turbidity determination and temperature variation within the water body. Other tests carried out included dissolved oxygen content and pH levels. Three sampling stations were selected randomly: one for testing inflow discharge, one for assessing effects of intense human activities and the last one for assessing the outflow discharge. A total of thirty eight (38) water samples were collected at different depths during winter and summer months.

The driving force behind the choice of Von Bach dam is the fact that there are very few fresh water sources available to meet the ever increasing demands of the country's growing population and industrial activities. These few sources are also at risk from pollution resulting from uncontrolled waste dumping, poorly managed agricultural lands, industrial effluents and air borne pollutants. Von Bach Dam, located on Swakop River seven kilometers from Okahandja, town is the main source of fresh water for the largest town and capital city of the country, Windhoek. The dam is a recreation facility which also serves as a water source not just for Windhoek but also for the nearby Okahandja town.

Von Bach Dam has a capacity 48.5 Mm^3. It is a popular venue for aquatic recreation for activities such as water skiing, yachting, windsurfing, boating as well as angling. At Von Bach Dam there are bungalows and camping facilities on the south eastern banks of the dam. Wild animals including kudu provide added attraction. The catchment area of Von Bach Dam, used mainly for livestock farming and small-scale crop cultivation to produce food for family and friends, has seasonal rivers which cut off villages such as Ovitoto during the rainy season when they are in flood.

Anthropogenic activities which take place in a catchment area are assumed to affect the quality of the water in rivers and storage dams. Human activities are considered to be the highest contributing factor in water pollution of water bodies all over the world. In any given river basin, human activities emanating from different sources affect water characteristics particularly those taking place in the upper catchment area.

Overall assessment of drinking water system should take into consideration any historical water quality data that assists in understanding sources of water characteristics and drinking water system performance both over time and following specific events like excessively high rainfall. The efficiency in managing water resources and potentially polluting human activities in the catchment will influence water quality downstream as well as groundwater aquifers.

Turbidity of the water is important in quality monitoring because this is related to cleanliness (aesthetically) of the water. Turbidity is caused mainly by high concentrations of biota such as phytoplankton and sediments. Waters with low concentrations of total suspended solids are clearer and less turbid than those with high total suspended solids. Turbidity as a water quality parameter affects the aquatic system as it can alter light intensities in a water column thus potentially altering potential rates of photosynthesis and the distribution of organisms within the water column. Lowered rates of photosynthesis may in turn affect the levels of dissolved oxygen available in a water body, thus affecting large organisms such as fish. Sedimentation increases the turbidity of water in a reservoir (dam). Some sediments originating from the catchment's top soil following bad cultivation practices introduce nutrients into the river and eventually into a reservoir, dam or lake and thus affect primary producers in the plankton by reducing light penetration to the lower layers. Eventually this alters the composition of benthic communities.

Dissolved oxygen analysis is a key test in water pollution and waste water treatment process control since it is a key determinant of survival of most aquatic organisms. It is vital in the process of cellular respiration and without sufficient dissolved oxygen most aquatic life would not survive. Some organisms require high amounts of dissolved oxygen than others. Aquatic plant populations, rainfalls, rocks on the river bed, time of day, water velocity and water temperature are contributors to total dissolved oxygen. It is documented that dissolved oxygen in a water body should not exceed 110 % of the concentration of oxygen in the air because at certain concentrations it could be harmful to aquatic life.

Water pH in a body of water is affected by the age of the water body because of the chemicals discharged into it over time by communities and industries. Most lakes and dams/reservoirs are basic when they are first formed and become acidic with time due the buildup of organic materials. Surface waters receive a variety of organisms discharged in municipal wastewater effluents, industrial wastes and agricultural activities. Water temperature affects and accelerates the growth of adapted organisms in the water body. Microbial growth is not only keyed to bacterial strains that quickly adjust to limited nutrient sources, but also to water temperature.

Coliform bacteria are used as indicator organism in assessing the quality of the water and the presence of these bacteria indicates that pollution has occurred which can be associated with fecal contamination from man or other warm blooded animals (Gronewold and Wolper 2008). The characteristics of these bacteria include all aerobic and facultative anaerobic gram-negative, non-spore forming, rod-shape bacteria. This bacteria ferment lactose to produce a dark colony with a metallic sheen. The sheen may cover the entire colony and may appear only in the central area or on the periphery.

Testing water for all possible pathogens is complex, time-consuming, and expensive. However it is relatively easy and inexpensive to test for coliform bacteria. There are three different groups of coliform bacteria; each has a different level of risk. Total coliform, fecal coliform, and *E. coli* are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. *E. coli* is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform and if it appears that total coliform is present, the sample will also be tested for either fecal coliform or *E. coli*, depending on the lab testing method.

Reviewed Literature

Nowadays most river basins are to some extent subjected to the effect of the human economic activity (Ismaiylov et al. 2007). The changes in their runoff can be caused by both a direct impact on it and changes in the conditions of its formation resulting from an impact on the physiographic conditions (topography, soils, vegetation, etc.). It is generally true that a minimum quality of surface water must be ensured in order to maintain property self-purification (Rump and Krest 1992). In this report it is stated that the degree of pollution always parallels changes in the ecological situation.

Water quality in adjacent streams or upper or lower reaches of the same stream typically exhibit similar trends (Chang 2008). In this study Chang shows that the spatial patterns of nutrient concentrations confirm the influence of urban land cover on stream water quality. He stated that, watersheds that have been disturbed by deforestation and urbanization are less able to process these pollutants because of a reduction in microbes and processes that naturally work to immobilize nutrients. He reports that, some forms of nitrogen or phosphorus show elevated concentrations as flow rises due to a flushing effect.

The environmental state of water bodies is affected not so much by particular chemical elements as by complexes of elements that are simultaneously present in water and bottom sediments (BS) (Klenkin et al. 2008). Their research found out that the comparative assessment of BS pollution in different regions of aquatic ecosystems and the investigation of sources of the increased anthropogenic pollution are only possible with the compensation for differences in the granulometric composition of BS. River water runoff is regarded as the most available resource that renews every year (Magritskii 2008). Magritskii suggested that this property of river water makes it most significant for practice as compared with water resources that renew more slowly or groundwater that renew annually.

In his analysis, Magritskii found out that, the effect of economic activity on the river basins of North European and Asian parts of Russia is much weaker. He stated that the rate of intensification of sulfate reduction in water bodies is a sign of a stronger anthropogenic impact on the environment and natural water bodies. On the other hand, other researchers including Chicherina and Leonov in their work dated 2008, state that the rate of sulfate reduction (SRR) is a representative characteristic allowing one to control anthropogenic pollution and eutrophication processes in water bodies (Leonov and Chicherina 2007).

The productivity growth of a water body is affected by an increase in phosphorus release from bottom sediments (Martynova 2008). According to Martynova it is believed that the main reason for the increase of the internal phosphorus load in a eutrophic water body is the expansion of the area under anaerobic sediments, from which phosphates absorbed by iron compounds under aerobic conditions are released. Additionally, biogenic substances (N and P compounds), which are present in natural waters, play a very important role in the processes taking place in streams and largely effect the chemical composition and physical properties of water (Samarina 2008). In this report it is stated that on one hand, the need to restrict eutrophication requires the identification of links between biogenic substances flow formed at the watershed and on the other hand, the dynamics of the water body eutrophication.

According to the study conducted by Samarina in (2008), the destruction of high-molecular organic compounds of natural and anthropogenic origin intensifies the contamination of a water body and disturbs the normal vital activity of animal and plant organisms. In this study, it is stated that, analyzing the anthropogenic factors resulting in the appearance of phosphorus and different mineral forms of nitrogen in the streams in industrially developed areas of Central Chernozem region, the following factors could be identified: the intense development of national economy, accompanied by an increase in the number of settlements in the region, points to an abrupt increase in the amount of domestic and industrial effluents, as well as uncontrolled washes off from settlements and industrial zones within the watershed area. Meanwhile in his study conducted in 2007, Jing Zhang argues that industrialization and urbanization along the coastal population centers have brought great changes in the land cover and natural material fluxes from watersheds to receiving bays and estuaries.

Generally, the temperature of the water under treatment is another factor to consider in the operation of a sedimentation basin (Goula et al. 2008). It is stated that, usually, a wastewater treatment plant has the highest flow demand in the summer, whereas when the water is colder, the flow in the plant is at its lowest. As ecosystems with slow water circulation, lakes and reservoirs (dams) have similar formation and development regularities (Martynova 2006). Martynova argues that, as compared to natural lakes, reservoirs have larger catchment area and higher rate of water circulation; they are subjected to a higher pollutant load and have a higher capacity of retaining all sorts of human-induced contaminants.

Elsewhere, the environments receiving runoff from urban areas have been reported to experience an increase in their concentrations of suspended sediments, nutrients and metals (Pecorari et al. 2006). According to them, rivers, lakes and other water bodies are frequently located in urbanized areas and such waters are not only used for recreational purposes, but usually act as collectors of diverse types of effluents. Pecorari et al. stated that traditionally, few limnologists have paid attention to the effects of urbanization on the ecology of these impacted aquatic systems. However, it is a well-known fact that urbanization causes great changes in the hydrology, geomorphology and water quality, which can be stronger than the impacts caused by other uses of the land such as agriculture and forestation.

Data Collection and Analysis

Non-probability sampling techniques were used, where the probability of any particular member of the population being chosen is unknown. The selection of sampling units is arbitrary as researchers rely heavily on personal judgment. In this study, the sample size was selected in such a way that it represented the characteristic of the total population. Nineteen (19) water samples were collected on each trip, the first samples were collected during winter (June 2008) and the second samples were collected during summer (September 2008).

Water samples were collected at each of the three selected stations, two at each depth using a niskin bottle with a depth finder and an attached weight. Water from the *niskin* bottle was poured into sampling bottles (glass bottle 250 ml) and the sample bottles were labeled before they were stored in the cooler box at a temperature below 10 °C. Samples in the cooler box were taken to the laboratory where they were refrigerated at a temperature below 10 °C and analyzed within

Table 4.1 Average bacteria density for summer season

Station	Depth (m)	Heterotrophic plate count (CFU/1 ml)	Total coliform (CFU/100 ml)	Fecal coliform (CFU/100 ml)	*E. coli* presence/absence
Inflow	0	2026.5	146.7	184.3	Present
Ski club	0	736	30.7	1.7	Present
Outflow	0	362.5	27.3	0.7	Present
	9	373.5	*79*	1.3	Present
	18	395	36.7	0.7	Present
Total average		778.7	64.1	37.7	

24 h to test for total coilforms, fecal coilforms, and pH. Parameters such as, dissolved oxygen, turbidity and temperature were measured and recorded in the field. To measure Temperature and Dissolved oxygen, an oxygen meter was used after calibration and a secchi disk was used to determine turbidity.

The data was subjected to statistical analysis using a two way-ANOVA. This analysis revealed that there was a significant difference in temperature readings at all the stations in both winter and summer at 5 % significance level. The analysis also revealed that the water temperature readings were significantly different at 5 % significance level. Dissolved Oxygen level analysis revealed that there was no significant difference in dissolved oxygen levels for winter and summer months.

Collected data on turbidity, pH and heterotrophic counts bacteria at all the three stations were also subjected to statistical analysis using ANOVA. The analysis showed that there was no statistical difference in turbidity of the dam water at all stations during winter and summer at 5 % significance level. Similarly, no statistical difference in pH of the water was recorded for all the stations for winter and summer months at 5 % significance level and that the heterotrophic plate bacteria count were the same in both winter and summer. Statistical analysis for total coliform counts bacteria from all the stations were not statistically different from each other at 5 % significance level.

However, statistical analysis of fecal coliform counts revealed that there was a marked difference on samples collected from the three stations during winter and summer at 5 % significance level. Samples from the inflow water station for both winter and summer contained *E. coli* while the water for the other two stations showed presence of *E. coli* only during summer months (Table 4.1).

Heterotrophic Plate Count Bacteria (CFU/1 ml)

The average density of the heterotrophic plate counts bacteria are shown in Tables 4.1 and 4.2. The winter results show that the average density was higher at the Ski Club station at 0 m depth compared to the Inflow and Outflow stations at

Table 4.2 Average bacterial density for winter season

Station	Depth (m)	Heterotrophic plate count (CFU/1 ml)	Total coliform (CFU/100 ml)	Fecal coliform (CFU/100 ml)	*E. coli* presence/absence
Inflow	0	850	87.7	9.7	Present
Ski club	0	1400	70.3	1.7	Present
Outflow	0	750	118	0	Absent
	9	450	102	4	Present
	18	350	116.3	4.3	Present
Total		760	98.9	3.9	

the same depth. On the other hand, in Table 4.2 the average heterotrophic plate count bacteria were higher at the Inflow Station at 0 m depth.

The inflow station in Table 4.2 shows higher total coliform counts bacteria compared to the other two stations. The temperature differences during winter and summer affects the average total coliforms as indicated in the two tables where the total coliform counts are more in winter than in summer. Despite the low temperatures in winter, the population of bacteria is one to one and half orders of magnitude than in summer. The Inflow station had a higher count of fecal coliforms in both winter and summer. The total average of coliform counts was higher in summer than in winter giving an inverse proportion relationship between total coliform and fecal coliform. *E. coli* was confirmed at all stations during summer at all depths except at the Outflow during winter.

As expected the water temperature was higher during summer than during winter at the Outflow Station, however the rate of decrease with depth was faster in summer than during winter (Fig. 4.1). The water temperature at the Inflow and Ski Club Stations showed low variations with depth and as such had no significant bearing on the water of Von Bach dam.

The Outflow Station recorded higher levels of dissolved oxygen at the surface water in summer than in winter. The dissolved oxygen dropped rapidly with depth during the season. Comparatively, in winter the water dissolved oxygen decreased more slowly with depth than during summer (Fig. 4.2).

The effect of water temperature on bacteria counts was clearly demonstrated by the bacteria average density which was much lower at the surface during summer compared to the winter season when there was a rapid increase of bacteria count with depth. This supports the fact that the higher the temperature the lower the bacteria replication process (Dolgonosov et al. 2006).

The Outflow Station experienced rapid drop of dissolved oxygen with depth during summer and a more gradual drop during winter. This difference can be explained by the fact that low surface water temperatures in winter supports fast growth in bacteria in all depths as compared to summer scenario when temperatures are high at the surface but drop rapidly with depth thus supporting fast growth of bacteria at greater depths (Fig. 4.3). The dissolved Oxygen levels at the

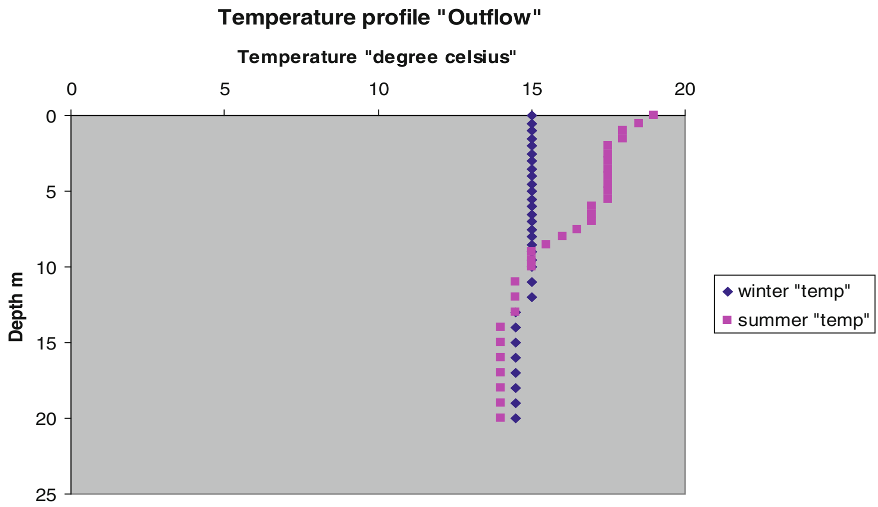

Fig. 4.1 Winter and summer temperature profile at the outflow station

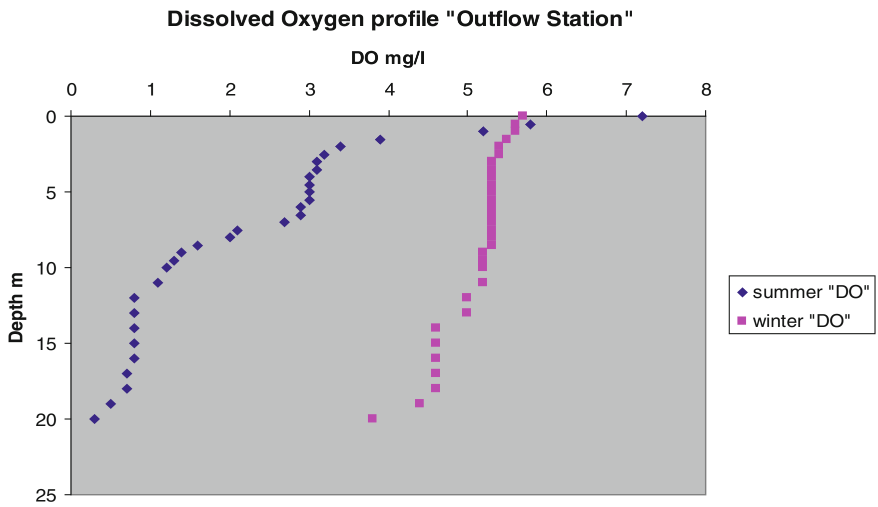

Fig. 4.2 Winter and summer dissolved oxygen at the outflow station

Inflow and Ski Club stations in both summer and winter showed fewer constant variations with depth (Figs. 4.3 and 4.4).

Turbidity levels were higher at the Inflow Station during winter than other stations. This was caused mainly by in flowing water from the catchment area which suffers from overgrazing and is characterized by high losses of top soil loosed by continuous trampling by large herds of livestock. This high sediment

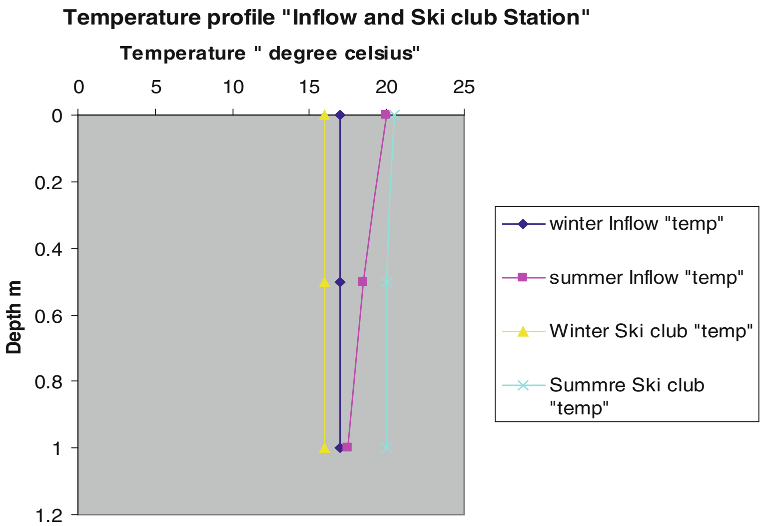

Fig. 4.3 Summer and winter temperature profiles at the inflow and ski club stations

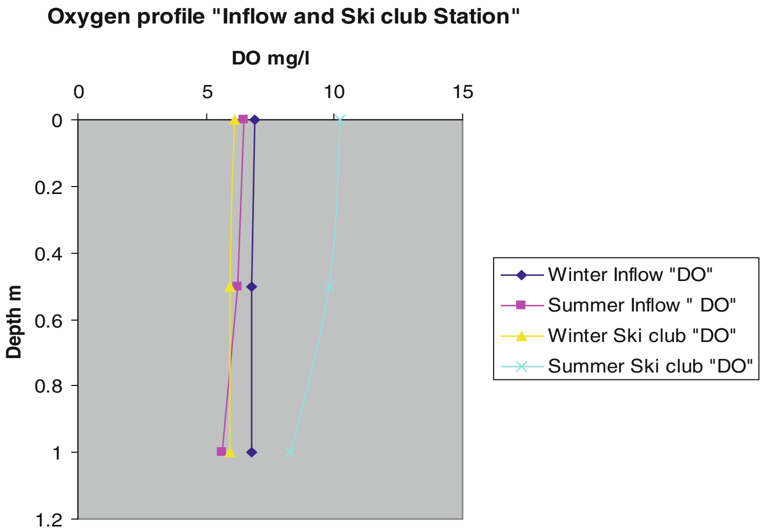

Fig. 4.4 Summer and winter oxygen profiles at the inflow and ski club stations

concentration can be linked with the low counts of coliform bacteria at the Inflow Station because when the level of turbidity increases, the water loses its ability to support a diversity of aquatic organisms. Water turbidity has a direct relationship with temperature and dissolved oxygen because when turbidity level is high, the suspended particles absorb more heat from the sunlight and lead to an increase in water temperature which results in lower dissolved oxygen in the water. Hence the higher the turbidity the lower the bacterial counts.

The water turbidity level was higher during winter at the inflow station as the secchi disk's color disappeared at 31 cm deep compared to that of summer when the color disappeared at 46 cm deep; a difference of 15 cm. The Outflow Station showed turbidity content at 72 cm and Ski Club showed turbidity at 87 cm while during summer the turbidity content was observed at 38 and 50 cm at the Outflow and Ski Club stations respectively.

The pH values of the water at the Inflow Station in winter and summer were constant while at the Ski Club and Outflow Stations some variations were observed. This is explained by the effluents from the residential and resort bungalows at the Ski Club Station.

According to water classifications based on NAMWATER standard guidelines for drinking water, water at the Ski Club Station is fit for human consumption during all seasons. However water at the Inflow Station is fit for human consumption during summer because the bacterial counts were in group B and C (Appendix 4.1).

Discussion

The major sources of microbial pollution to the dam water emanate from human and warm-blooded animal excrements that enter into water bodies with municipal wastewaters and drains from cattle farms and areas polluted by manure (Dolgonosov et al. 2006). Heterotrophic plate count consists of diverse groups of microorganisms that have wide range of metabolic capabilities and culture requirements and constitute a wide range of risks to public health (Lechevallier and Mcfeters 1985). The growth of many heterotrophic is more pronounced than the coliform subset of this population, often providing abrupt surges in density during summer (Geldreich et al. 1977). Heterotrophic plate counts bacteria cause health risk in patients who are in hospitals, clinics as well as at home. Some species and strains of Psedomonas, Bacillus and sarcina suppress coliform bacteria detection in water; this suppression is due to the increase in heterotrophic plate counts bacteria. Fecal and total coliform bacteria are indicators of potential fecal pollution and water-borne pathogenic threats to human health.

In this study, high coliform bacteria counts recorded at the Inflow Station during both seasons is an indicator of pollutants gathered by rain water from the catchment area and delivered to the streams flowing into Von Bach dam. The presence of the bacteria at the other two stations can be explained by the discharge from the resort bungalows and directly from the people who swim and bathe in the water body. Animals who are watered directly from the dam could also be a contributor to this direct pollution through their droppings.

Studies done elsewhere have demonstrated that there are low population of microorganisms in summer and autumn which can be due to phytoplankton blooming bringing about an increase in pH values. Raised pH values suppress vital activity of bacteria flora (Dolgonosov et al. 2006). The observed high pH value (close to 10) at both the Ski Club and the Outflow Stations in summer confirms this observation documented in the report by Dolgonosov et al. Combined with high temperatures and high turbidity, such an occurrence could have contributed to the low summer coliform counts at the two stations at 0 m depth. *E. coli* was confirmed at the Inflow Station in both seasons and at the Ski Club Station during summer.

Bacterial count for heterotrophic plate counts, total coliform, and fecal coliform shows high counts in summer at the Inflow Station with lower content of turbidity than it was in winter with highly turbid water. This shows that, turbidity plays a very important role in bacterial growth and they are inversely related. According to the study conducted by Martynova in 2006 it was confirmed that the higher the plankton production (and the higher the rate of its destruction in the water column, which lags behind the increase in the productivity), the higher the rate of organic matter accumulation, and, respectively, the higher the sedimentation rate. The high population of coliforms in winter could be explained by high release of organic matter at the catchment surface because of decay of dead plant material accumulated in summer and delivered by surface waters into the estuary. This observation is well indicated in this study, whereby coliform counts at the Inflow Station was high in summer compared to the counts during winter. The reason could be that, the decay of dead plant material was taking place in summer while the water has already reached the inflow station from the catchment area. During winter the outflow station was inundated by dead plant material and since the decay process is very slow in winter, few counts of coliform (fecal and total) were found.

Dissolved Oxygen is used by bacteria during the decaying process of organic matter in the aquatic system. Dissolved Oxygen is also produced during the photosynthesis process by phytoplankton in the aquatic system as a by-product. Possible increase in organic matter in the Von Bach dam could be through soil losses resulting from poor agricultural practices in the catchment area, land clearing for building structures around the dam and through direct disposal of organic matter by people frequenting the dam to engage in recreational activities. The consequences of these activities may have contributed towards lowering oxygen levels in the dam water. Elsewhere, it has been documented that aquatic ecosystems changes were brought about by the changes in the relative contribution of major water pathways and biotic concentrations originating from human activities in the watershed (Zhang 2007).

Turbidity which depicts clear state of the water is mainly caused by the sediment released from the catchment area and from activities around the dam. This sediment carries nutrients into the water body resulting in rapid bacteria growths. On the other hand, an increase in the pH of water lowers the growth of microorganisms such as bacteria. The rise in pH values is caused by the increase in organic material within the water body because when these materials decompose, carbon dioxide is released and the carbon dioxide combines with water to form carbon acid. Even though the acid formed is weak, large amount of this can lower the water pH. Dumping of chemicals into the water by individuals, industries and communities in the watershed can affect the water pH as well. Chemicals contained in shampoos can affect the water quality; these chemicals are frequently used by residents occupying holiday bungalows around the dam and those using the ablution facilities of the recreational infrastructure. Daily visitors to the dam can also contribute to this through dumping. This explains the variations of the pH values at the Ski Club and Outflow Stations throughout the two seasons against the constant pH values at the Inflow Station over the two seasons.

Conclusions

Natural waters become polluted when the polluting material upsets the natural balance of microorganisms, plants and animals living near or in the water body or makes the water unsafe for human consumption or for recreation. In this article, Chan et al. also stated that natural water may contain a wide variety of microorganisms; in fact it is not unlikely that one might find representatives of many of the major categories of microorganisms in a specimen from such sources. Therefore monitoring the water quality overtime being it seasonal, monthly or even weekly may give conclusive evidence on the quality of the water.

In this study on Von Bach Dam, the bacteriological analysis of fecal coliform indicates that there is pollution emanating from human activities since the results from some of the water samples tested for *E. coli* confirmed the presence of these microorganisms. It is assumed that water at these stations was contaminated by human activities both in the catchment area and around the dam. However, it should be noted that, not all the fecal coliform counts were from human and animal intestines as it was observed in the entire confirmation test for *E. coli* where some of the samples were negative results (brown and orange color). The higher detection of coliform bacteria at the Inflow Station could be attributed to the increase in nutrients load coming into the dam from the catchment area.

Heterotrophic plate count is not sensitive to human activities, as this test is for diverse groups of microorganisms but the water with higher level of heterotrophic plate count when consumed can cause illness or spoil food. The results from this test indicated that, the water at all the stations were of little risk to human health, since the counts were within the limits stipulated by NAMWATER as of little risk to human health. The pH of the water during summer and winter did not indicate potential harmful effects to human health because the pH levels results were within the limits of the NAMWATER standards for drinking water. Organic matter and soil sediments reaching the dam from the catchment area and from construction around the dam were the main indicators of anthropogenic activities affecting the water quality in Von Bach Dam.

Organic matter in the dam affects aquatic organisms by altering the temperature and dissolved oxygen levels upon which the aquatic organisms depend on for growth. Soil sediments and the organic matter values were found to be the major contributing factors in raising the dam water turbidity. Chemicals from shampoos and other cosmetics used by frequent visitors to the dam for recreational activities were found to be responsible for the elevated pH values particularly during summer months.

Recommendations

While this study generated some useful data which pointed to an indication of possible pollution to Von Bach Dam, it is recommended that for effective assessment of the impacts of anthropogenic activities on the dam water, more intensive testing should be carried out where more sampling stations would be established and more water samples collected using more sophisticated and accurate instruments that will afford higher precision.

It is also recommended that NAMWATER as the managing agent charged with providing potable drinking water to the country's population, should carefully address the dangers of waste water disposal particularly that which contain chemicals found in cosmetics. Over time these chemicals would accumulate to be a major threat to the balance of the aquatic ecosystem. These imbalances may affect the water quality in the long run so as to increase water purification costs.

Furthermore, it is recommended that more effective disposal methods of refuse from building construction around the dam should be put in place so as to prevent accumulation of shrubs and grass in the dam water which then lowers the amount of light penetrating the water body which deprives the light and energy required by phytoplankton for photosynthesis; it also increased the temperature of the surface water.

Lastly, it is recommended that periodic cleaning to remove debris should be instituted. Debris and organic matter reaching the dam from the catchment area accumulates at the Outflow Station which raises nutrients load that is likely to lead to an increase in the growth of phytoplankton. Rapid phytoplankton growth leads to algal blooms which affects the appearance of the water and kills aquatic organisms by preventing light penetration to the benthic layer of the water body. Debris affects the aquatic ecosystem by altering the pH of the water, temperature, dissolved oxygen, light intensity and turbidity. Thus filtration structures should be installed just above the inflow points to minimize the quantity of debris entering the water body from the catchment area.

Appendix 4.1: Water Classifications Based on NAMWATER Standard Guidelines for Drinking Water

The classification Consists of four groups:

Group A Water with an excellent quality

Group B water with good quality

Group C Water with low health risk
Group D Water with high risk, which is unsuitable for human consumption.

Summer standards

Stations (summer)	Inflow				Ski club				Outflow			
Limits to groups	A	B	C	D	A	B	C	D	A	B	C	D
pH	8.6						9.6				9.3	
Turbidity (Secchi cm)	*	*	*	*	*	*	*	*	*	*	*	*
Dissolved oxygen (mg/l)	*	*	*	*	*	*	*	*	*	*	*	*
Temp (°C)	*	*	*	*	*	*	*	*	*	*	*	*
Heterotrophic plate count (cfu/1 ml)			2027			736				362.5		
Total Coliform (cfu/100 ml)	Beyond limits						30.3			24		
Fecal Coliform (cfu/100 ml)	Beyond limits					1.7				0.7		
E. coli (presence or absence)	*	*	*	*	*	*	*	*	*	*	*	*

Star (*) indicate water quality parameters which are not in NAMWATER standard guidelines

Winter standards

Stations (winter)	Inflow				Ski club				Outflow			
Limits to groups	A	B	C	D	A	B	C	D	A	B	C	D
pH	8.5				8				7.5			
Turbidity (Secchi cm)	*	*	*	*	*	*	*	*	*	*	*	*
Dissolved oxygen (mg/l)	*	*	*	*	*	*	*	*	*	*	*	*
Temp (°C)	*	*	*	*	*	*	*	*	*	*	*	*
Heterotrophic plate count (cfu/1 ml)		850					1400			750		
Total Coliform (cfu/100 ml)			87.7				70.3		Beyond Limits			
Fecal Coliform (cfu/100 ml)			9.67			1.67			0			
E. coli (presence or absence)	*	*	*	*	*	*	*	*	*	*	*	*

Star (*) indicate water quality parameters which are not in NAMWATER standard guidelines. Water at the ski club station meets the NAMWATER standards in all seasons because all the measured parameters fall in groups which are less health-risk to human beings. The inflow station water was also less risky to human health because the bacteria counts were in groups B and C

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Chapter 5
The Effects of Water Transfer from Swakoppoort and Omatako Dams on the Water Quality of Von Bach Dam, Namibia

J. J. Sirunda and D. Mazvimavi

Abstract This chapter presents the outcome of research conducted in Otjozondjupa region, central Namibia on the effects of water transfers from two storage dams (Swakoppoort and Omatako Dams) to augment water volume in a third dam (Von Bach Dam) which is located closer to a purification plant. The transfers are strategically made to bring water closer to the purification plant and more important to limit evaporation losses from the wider and shallower dams; Von Bach Dam is much narrower and deeper than the other two dams which together, constitute the source of water for the expansive residential area and industrial hub located in the capital city of Windhoek and its environs. The study investigates water quality in the three dams and analyses the effects of water transferred and possible effects on water treatment costs. Research findings are discussed and analyzed using relevant models for predicting water quality changes. The results from the secchi disk depth measurements and the analysis of turbidity, dissolved oxygen; iron, total phosphorus, ammonia (NH_4–N) and chlorophyll *a* indicate that there were significant negative effects resulting from the water transfers. Other parameters tested indicate that there were no statistically significant differences in the three dams.

Keywords Algal bloom · Eutrophication · Water quality models · Stratification · Inter-basin water transfers

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Introduction

The aim of the study was to throw light on how water transfers from the two storage dams (Swakoppoort Dam and Omatako Dam) into the recipient dam (Von Bach Dam) affect water quality in the recipient dam and effects the transfers exert on purification costs. The purpose of the transfers is to limit evaporation losses from the wider and shallower dams and also to bring water closer to the purification plant. Von Bach Dam, constructed in 1978 for supplying water to Windhoek has a smaller surface area (4.9 km^2) and lower evaporation losses (2254 mm per year) compared to Swakoppoort and Omatako Dams which have much greater surface areas (Table 5.1). Both Swakoppoort and Von Bach Dam are on the Swakop River while Omatako Dam is on the Omatako River. Among the three dams, Swakoppoort Dam with a catchment area of 5480 km^2, has a capacity of 63.5 Mm^3 and a low annual rainfall of 350 mm per year while the Omatako Dam has the highest evaporation loss per surface area (2205 mm per year) compared to the other two dams.

Prior to this study, there existed a gap in knowledge on the effects of water transfers on water quality in Von Bach Dam as there had been no previous studies on the subject. To determine the effect of water transfer on the water quality parameters of Von Bach Dam, three research questions were investigated:-

i) Does the quality of water in the three dams differ greatly?
ii) How is the quality of water in Von Bach Dam influenced by water transfers?
iii) Is the treatment of water from Von Bach Dam affected by the water transfers?

The three dams are built across ephemeral rivers; they seldom spill as they are designed to store up to three times the mean annual runoff. Water quality in these storages is affected by the long retention period, high evaporation losses and intermittent inflow from the catchments. Four sampling stations were established in Von Bach Dam, one in Swakoppoort Dam, and one in Omatako Dam. Water samples were collected on a weekly basis. Over and above collecting water samples from the established stations, senior officers responsible for water treatment at

Table 5.1 Characteristics of Swakoppoort, Von Bach, and Omatako Dams

Features	Von Bach Dam	Swakoppoort Dam	Omatako Dam
River	Swakop River	Swakop River	Omatako River
Capacity (Mm^3)	48.56	63.48	43.50
Max. Depth (m)	29	30	11
Evapo.Losses (mm/a)	2254	2275	2205
Ann.rainfall (mm/yr)	370	350	380
Surface area (FSC) (km^2)	4.89	7.81	12.55
Catchment area size (km^2)	2 920	5 480	5 320
Geology of the areas	Schist and granite	Schists and granite	Sands and granite (calcrete)
Year completed	1970	1977	1982

FSC full supply capacity

Von Bach Dam were interviewed on possible water treatment problems arising from the water transfers. Descriptive statistics, ANOVA and correlation were carried out to analyze the data. Possible effects of upstream land use practices, catchment geology and water stratification were taken into account.

Reviewed Literature

Water quality is a term used to express the suitability of water to sustain a variety of uses and processes (Maybeck et al. 1996; Oberholster et al. 2009). Land use activities such as agriculture, deforestation, inter-basin water transfers, mining, and wastewater discharges and natural factors such as climatic, hydrologic and geologic conditions affect the quality of water bodies (Kemka et al. 2006; Out et al. 2010; Nyenje et al. 2010). For example, the water quality of Lake Loskop in South Africa, has been affected by acid mine drainage and high nutrient concentration from its catchment area (Oberholster et al. 2009). In Lake Victoria, Kenya, the water quality has been affected by the increase in temperature due to global warming by 0.9 °C from 1960 to 1990 (Marshall et al. 2009). Socio-economic activities such as forest removal for urban development, and disposal of wastewater adversely affect water quality (Olago and Odada 2007; Oberholster and Ashton 2008). It is thus desirable to monitor the activities in the catchment area of storage dams so as to determine necessary management requirements so that water transfer does not adversely affect the receiving water body or a distribution system that requires augmentation.

Water quality management plans for pollution control are being implemented world-wide to minimize the effects of point and non-point sources of water pollution. For example, in the Latin American region, less than 10 % of point sources of pollution are managed in an environmentally acceptable manner (sewage discharge, agricultural waste discharge and oil spills). Non-point sources of pollution are of major concern in the Organization for Economic Co-operation and Development (OECD) countries (Biswas and Tortajada 2006). In the Rotorua District of New Zealand, nine to twelve lakes are heavily polluted with nutrients. Management plans such as the upgrading of waste treatment facilities, and dosing tributary streams with alum, have been instituted to improve the water quality in these lakes (Burns et al. 2009).

Millennium Development Goal 7c aiming to half the proportion of people without sustainable access to safe drinking water by 2015 will not be achieved if water pollution is not controlled. While 17 % of the world population had no access to improved drinking water sources in 2004, the plan is to reduce this to 13 % by 2015 to meet the Millennium Development Goal 7c. Between 1990 and 2004, the world population with access to improved drinking water sources increased from 78 to 83 %. During this period, about 30 % of the people without access to improved drinking water lived in Sub-Saharan Africa, 27 % in East Asia and 23 % in Southern Asia (WHO and UNICEF 2006). Thus efforts to properly manage water quality by these regions including Southern Africa were recommended in order to raise access to drinking water.

In a document on the water vision for African countries, it is recommended that water for sustaining ecosystems and biodiversity should be adequate in quantity and quality and that there should be a sustainable access to safe and adequate water supply and sanitation to meet basic needs of all by 2025 (African Water Vision for 2025 n.d). The Southern Africa Development Community (SADC) Water Policy document also insists that SADC countries should harmonize and uphold common minimum standards of water quality in a shared water courses and that member states should individually and collectively adopt necessary measures to prevent and control pollution (point and non-point sources) of ground and surface waters resulting from inland, coastal, or offshore activities (SADC 2006).

Water quality management at catchment level is important because this is where land use activities which affect water quality take place. Some of the countries in Southern Africa have embarked on implementing water quality management plans in keeping with SADC and MDG recommendations. For example, in South Africa, water quality management is being implemented at the catchment level as part of Integrated Water Resources Management (IWRM) (Pegram and Bath 1995; Howard et al. 2000). Monitoring of the effects of land use practices such as agriculture and human population growth on water quality is being carried out in the Mgeni River catchment, one of the major water sources for the country where the roles and responsibilities of the interested and affected parties in pollution identification are being clarified. Geographic Information System (GIS) is being used to determine catchment characteristics and land use impacts on water quality in the Crocodile River catchment to work out modalities of effectively managing the impact in an integrated manner (Ashton and Van Zyl 2000). Similarly in Zimbabwe, stakeholders' participation is being used to monitor water quality by assessing their indigenous knowledge on water taste, color and odor (Nare et al. 2006).

Inter-basin water transfer for quality improvement or quantity enhancement is practiced worldwide. In China, water transferred from the Yangtze River to Lake Taihu is reported to have improved the water quality of the lake; it has improved the total nitrogen, total phosphorus and chlorophyll *a*. (Hu et al. 2009). In South Africa, water transferred from Caledon River through Knellpoort Dam to Modder River adversely affected the dam water as it caused a decrease in light penetration and an increase in nutrients in Knellpoort Dam (Slabbert 2007). In Namibia, possible effects of water transferred from Swakoppoort and Omatako Dams into Von Bach Dam was of serious concern because it is feared that water transfers could affect the water quality in Von Bach Dam. These effects on the water quality of Von Bach Dam, the main source of fresh water for Windhoek's population and industries, were not known. Hence this study was undertaken to fill the gap in shedding light on how the water quality of Von Bach Dam is affected by water transfers from the two dams.

Customarily, lakes are expected to fulfill several functions including water supply for municipal and agricultural uses, as well as for recreation and fisheries.

These uses have in some cases conflicting water quality demands as the increase in population and industrialization have increased the range of requirements for water together with a greater demand on higher quality water (Chapman 1992; Rhodes et al. 2001). However, due to low levels of industrialization in Africa, changes in water quality of lakes does not present the same problem as in highly industrialized countries. On the other hand, land use activities in the catchments such as overgrazing, over-cultivation, and deforestation, affect the water quality of lakes particularly in Africa (Kitaka et al. 2002).

The geology of the catchment including land use activities in the catchment also affect water quality in lakes. Agricultural irrigation and industrial cooling require the least in terms of water quality while domestic use and specialized industrial processing have a high demand for high water quality. Effluents from these activities and inter-basin water transfers and discharge of untreated waste have a bearing on water quality. Therefore, considerable efforts should be made to control both point and non-point sources of pollution (Chapman 1992; Kitaka et al. 2002).

In a lake, the most important factor that influences water quality is stratification (Bartram & Balance 1996; Chapman 1992). Stratification occurs when the water has two different densities, one floating on top of the other. The difference in densities is caused by the temperature differences in the water layers. Water quality varies with the densities so that bottom layers have much lower oxygen content than upper layers. Oxygen gets depleted in the bottom layers during stratification causing substances such as ammonia, phosphate, sulphide, silicate, iron, and manganese compound to be released and diffuse from the sediments into the lower water layers (Robarts et al 1982; Bartram and Balance 1996; Breen 1983; Hart and Allanson 1984).

The most disturbing changes in water quality of lakes occur when the lake is enriched with nutrients such as nitrogen and particularly phosphorus from external and internal sources. This process known as eutrophication has been found to have adverse impacts on the water quality of lakes. While eutrophication is viewed as the natural ageing of lakes, the process is accelerated by external sources of nutrients resulting from human activities such as the disposal of municipal wastewater and crop farming in the catchment supplying nutrients to lakes (Oberholster and Ashton 2008; Ekholm and Krogerus 2003; Hart 2006; Van Ginkel 2004; Nhapi and Tirivarombo 2004).

The internal source of nutrients, particularly total phosphorus, is the sediment found at the bottom of the lake. In many lakes, sediments store significant amounts of total phosphorus. It is argued that even though phosphorus is at the bottom of the lake (i.e. lake sediment) it is only released from the sediment when suitable conditions arise. To ensure a proper recovery of water quality due to total phosphorus enrichment, both external and internal sources should be reduced (Dalkiran et al. 2006; Hart et al. 2003; Hart 2006).

Other researchers have found out that even though total phosphorus is released from the sediment, it may not be available for primary production to cause algal bloom in the epilimnion layer. Most of the total phosphorus released from the sediments during stratification is found in the hypolimnion layer below the thermocline where there are no algae available to utilize the total phosphorus. When the stratification breaks down, phosphorus becomes fixed by an oxidizing agent in the sediment causing it once again not to be available for phytoplankton in the epilimnion. Therefore, it seems that internal phosphorus loading contributes less to the eutrophication process of the water and the most effective way to control eutrophication in a lake is by reducing nutrients from external sources (Twinch and Breen 1980; Fred et al. 1978; Ekholm et al. 2000).

In Lake Chivero, Zimbabwe, an increase in nutrient loads of total phosphorus was found to be due to the discharge of effluent from a wastewater treatment plant where the Manyame River supplies a significant concentration of total phosphorus to Lake Chivero due to the sewer overflow in Chitungwiza, and the waste-stabilization pond effluent from Donnybrook and Ruwa sewage treatment works. The Marimba River in the sub-catchment of Lake Chivero was also found to supply a significant amount of phosphorus, ammonia and nitrate, especially in the part occupied by informal industrial and residential areas ((Nhapi et al. 2004; Mvungi et al. 2003).

Algal blooms create health hazards for humans or animals through the production of toxins that causes deterioration of water quality. Blue-green algae cause the most detrimental algal bloom. In Lake Victoria, Kenya, the bloom of 1986 was dominated by microcystis. Microcystis and anabaena are very efficient at utilizing available nutrients and cannot usually be controlled by nutrient deprivation as they are able to fix nitrogen from the atmosphere and require only about 10 μg/l of phosphate to form a bloom but they are vulnerable to light limitation. Therefore, the reduction of nutrients would not prevent algal bloom, although the extent of bloom may depend largely on nutrient availability (Reynolds & Walsby, 2008; Ochumba and Kibaara 2008; Kirke 2001).

Blue-green algae have vesicles inside vacuoles within their cells that they inflate with gas, thereby regulating their buoyancy in response to environmental conditions. This is an advantage over other algae as they have the ability to sink and rise at will and move to where nutrient and light levels are highest, usually towards the bottom of the euphotic zone, where they encounter conditions most favoring their growth. The formation of a bloom occurs when most of the algae possess excess buoyancy. Excess buoyancy is acquired when the photosynthetic rate is insufficient to develop the necessary turgor-pressure to cause collapse of the vacuoles (Reynolds and Walsby 2008).

Physical factors such as water column stability, water turbulence, and water temperature also control the occurrence of a bloom of algae. When turbulence of the water column is low, as it is in sheltered lakes, cyanobacteria can build up a dense population. However, if the turbulence of the water column is high (mixing depth much greater than euphotic depth) cyanobacteria are outcompeted. Moreover, blue-green algae form floating scum because they are generally not eaten by other aquatic organisms due to the toxins (secondary metabolite) which they produce (Steinberg and Hartmann 1988).

Algal blooms occur when there is a correct combination of nine factors: (i) elevated water temperature of >20 °C; (ii) lack of competition and predation; (iii) light; (iv) long residence time; (v) low flushing rate; (vi) nutrients;

(vii) strong vertical stratification; (viii) temperature and (ix) water column stability. The changes in water quality due to blooms of blue-green algae pose a problem for water treatment. The problems encountered during water treatment are identified as follows as (a) unpleasant smell and taste of water; (b) clogging of filters and pumps, and reduction in the carrying capacity of pipelines and canals; (c) reduced oxygen level in the water, thus affecting aquatic biota; (d) increase in the concentration of dissolved organic carbon, iron, ammonia and manganese in the water and (e) high turbidity in the water making the treatment of bacteria ineffective (Kirke 2001); Reynolds and Walsby 2008).

Models for Predicting Water Quality Changes

Water quality models are useful in describing or predicting the ecological state of a lake or river system. They are used in a situation where there are no monitoring data and in some situations they are used in combination with monitoring data to understand the changes in water quality due to different management strategies. There are different types of water quality models such as dynamic or empirical models and statistical or steady state models (Loucks et al. 2005; Rast et al. 1983; Tong and Chen 2001).

In Ben Chifley Dam, Bathurst, New South Wales, a conceptual model was developed to understand and to address causal factors and processes controlling blue-green algae (Rahman and Al Bakri n.d). The model provided a basis for the cost effective management strategies to control eutrophication and to minimize algal outbreaks. The model was developed on three components such as water quality, algae and sediment–water interaction.

In the East Fork Little Miami River Basin, the Better Assessment Science Integrating point and Nonpoint Sources (BASINS) mathematical model (i.e. dynamic model) was adopted to determine the effects of land use on water quality. The statistical analyses revealed that there was a significant relationship between land use and in-stream water quality, especially for nitrogen, phosphorus and fecal coliform. Agricultural land and impervious urban lands were found to produce a much higher level of nitrogen and phosphorus than other land surfaces (Ton and Chen 2001).

In Lake Edku, Northern Nile Delta, a water–sediment flux steady state model for total phosphorus was implemented to understand the geo-chemical behavior of total phosphorus in the water and sediment, and to calculate its concentration in the water and sediments. The model showed that the total phosphorus inputs into the lake were more than the outputs, which made the lake highly eutrophic. It was recommended that, reducing 2 % of total phosphorus in the lake sediment and a 15 % reduction of total phosphorus from each drain could act as an important solution for the quick recovery of the lake (Badr and Hussein 2010).

A steady state model for eutrophication control was developed for the Organisation for Economic Co-Operation and Development (OECD) countries by

Vollenweider and Joseph. The model defines the relationship between phosphorus loads and eutrophication related responses of water bodies (Rast et al. 1983). The model is used as a management tool in the assessment and control of eutrophication in lakes. A statistical relationship is developed between annual phosphorus loadings into a lake normalized by mean depths and hydraulic residence time to predict the lake total phosphorus concentration. The model was developed using data from over 200 water bodies in 20 states of OECD. The equation for the model is written as:

$$P = 1.55(LTw/z)/(1 + \sqrt{Tw})^{0.82}$$

Where:

P	predicted median annual lake total phosphorus (TP) concentration (mg/l)
L	total phosphorus load (mg/m^2/year)
Z	mean depth of the lake (m)
Tw	hydraulic retention time (years)
LTw/z	average concentration of total phosphorus in the inflow (mg/l)
Tw/z	water loadings (m/y)

The OECD model was developed based on the following assumptions:

- The model assumes a steady state condition in a completely "mixed reactor"
- It is unlikely that individual loading estimates are more accurate than ±35 %.
- The nutrients loading model gives an estimation of average conditions; local conditions may deviate considerably, temporally and spatially.
- The model assumes that the basin is open and that there is an annual water surplus or outflow from the lake.

The OECD model has been applied on South African dams such as Allemanskraal, Klipfontein, Klipvoor, Vaal, and Welbedacht. The accuracy of the model was assessed by comparing the predicted total phosphorus and the observed total phosphorus, where the predicted was not varying by more than 30 % of the observed (Harding 2008).

The effect of Inter-Basin Water Transfers on Water Quality of Recipient Lakes/Dams

When sources of nutrients are uncontrollable in a particular dam, inter-basin water transfers may be used to lower the concentration of nutrients to acceptable levels in the recipient dam. This was successfully done in Green Lake and Moses Lake in Washington. The surface area of Lake Green and Lake Moses is less than 40 km^2. Inter-basin water transfer has been used in some countries as a restoration method to improve water quality. In China, inter-basin water transfers improved the water quality of Lake Taihu, by lowering the concentration of total phosphorus, total nitrogen and chlorophyll a (Hu et al. 2009).

Apart from water transfers, other methods are also considered as restoration methods to improve water quality in lakes. Methods such as the reduction of nutrient loads, sediment dredging, wetland construction and bio-manipulation have been used in the restoration of aquatic ecosystems (Hu et al. 2009). These methods are slow at improving water quality. The transfer of water of low nutrient concentration to eutrophic small dams has a quick response in nutrient reduction. Hu and his colleagues further postulate that the method of water transfers is a cost-effective method. But the cost of water transfer as a restoration method varies from country to country.

In Southern Africa, water is transferred from one basin to another for a variety of reasons. For example water is transferred from the Caledon River through Knellpoort Dam to the Modder River. The water transfer scheme is called the *Novo* Water Transfer Scheme. It has been observed that the turbidity increases in Knellpoort Dam as a result of water transfer due to an increase in algae growth. Apart from turbidity, nitrate increased at the surface from 56.8 to 76.2 μg/l and at the bottom from 64.3 to 78 μg/l. Total phosphorus was found to have increased at the discharge point. Thus water transfers affect the water quality of receiving dams even though their effect is localised (Slabbert 2007). Other water transfers in Southern Africa are presented in Appendix 5.1.

As stated in earlier chapters, Namibia as a very dry country with extremely high temperatures, high evaporation rates and low rainfall is largely characterized by ephemeral rivers. The few perennial rivers are on international boundaries and thus shared with neighboring countries. Their use is governed by international water laws which require entering into trans-boundary agreements which are not easy to administer. Consequently, Namibia does not depend on these perennial rivers for water supply to the central part with high population and industries concentration. Namibia rely more on groundwater and the ephemeral rivers inside her borders to meet water supply requirements for the densely populated areas such as Windhoek.

The catchment areas of Swakoppoort, Von Bach and Omatako Dams are covered by acacia trees, shrub savanna, and broadleaved trees. The land uses in the Omatako Dam catchment is mainly agriculture on freehold land. The land uses in the catchment of Von Bach Dam are dominated by commercial livestock farming, game farming and villages. In the Swakoppoort Dam catchment, land use activities are mostly cattle and game farming on a commercial scale and urban settlements such as Okahandja and Windhoek Windhoek's sewage ponds and industries produce waste water which drains into Swakoppoort dam during the rainy season (Mendelsohn et al. 2002; Fig. 5.1).

Like in the case of the Omatako River, Swakop River receives high flows in January (2.5 m^3/s) and February (2.7 m^3/s), (Fig. 5.2) and flow cease soon after the rains during April/May. However, between 1980 and 2003, the water levels of the Swakop River were relatively low compared to those of the Omatako River. The highest flow during this period was about 27 Mm^3/yr during 1987 (Figs. 5.3, 5.4).

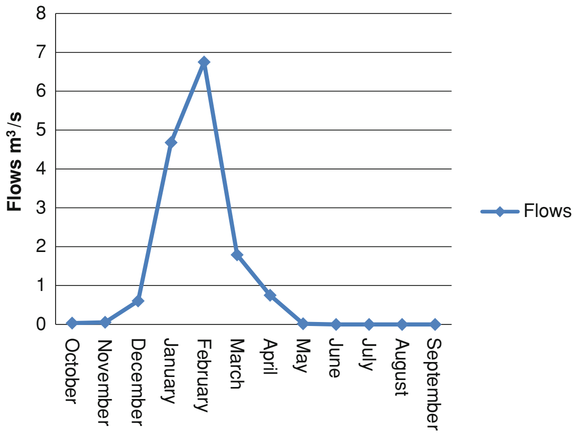

Fig. 5.1 Monthly flows on the Omatako River at Ousema site upstream of Omatako Dam. *Data source* Hydrology unit, Department of Water Affairs

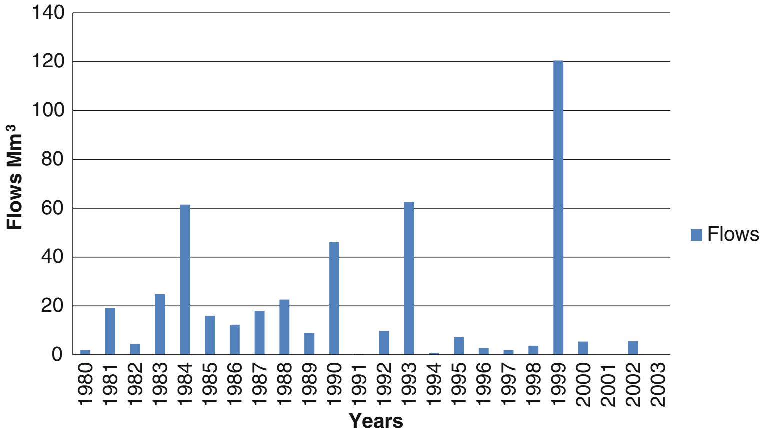

Fig. 5.2 Annual flows of the Omatako River at Ousema site upstream of Omatako Dam. *Data source* Hydrology unit, Department of Water Affairs

Research Methodology

Three groups of parameters (physical, chemical and biological) were assessed to gauge the water quality of the three dams. Physical and chemical water quality parameters such as temperature, dissolved oxygen, pH, turbidity, dissolved organic carbon, chlorophyll *a*, total nitrogen, ammonia, orthophosphate and total phosphorus were selected and biological water quality parameters (microcystis and anabaena) were selected for assessment. Six water sampling sites were selected in the three dams using a GPS.

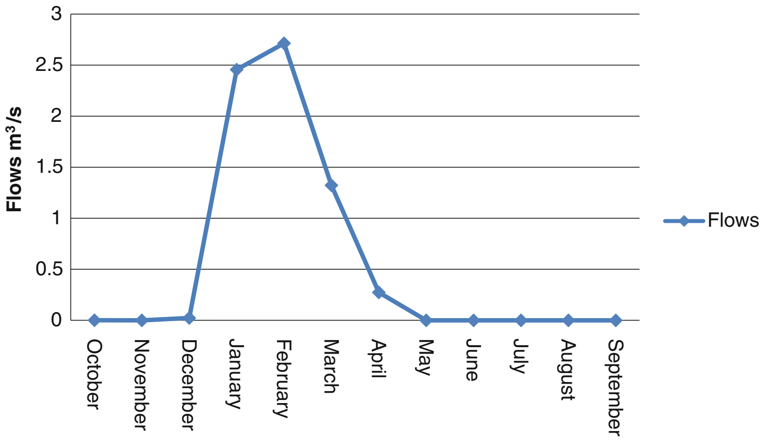

Fig. 5.3 Monthly flows on the Swakop River at Westfalenof site upstream of Von Bach and Swakoppoort Dams. *Data source* Hydrology unit, Department of Water Affairs

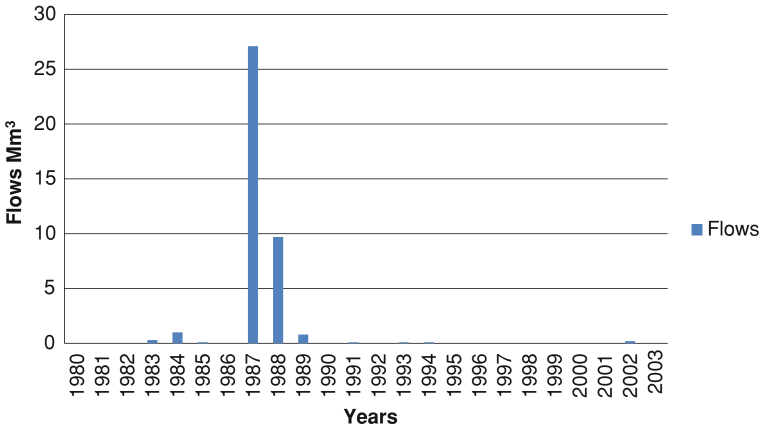

Fig. 5.4 Annual flows on the Swakop River at Westfalenhof site upstream of Von Bach and Swakoppoort Dams. *Data source* Hydrology unit, Department of Water Affairs

Water quality can be measured using chemical, physical and biological indicators; these indicators determine the state of the water quality and its suitability for various usage. The study monitored water quality characteristics of the three dams and the effects of transferred water on the water quality of the recipient dam, Von Bach Dam. The OECD countries model for predicting total phosphorus was adopted in this study due its successfully application in South African dams. Interviews with senior water treatment scientists attached to Von Bach water treatment plant were conducted to gauge any water treatment problems that could have resulted from water transfers from the other two dams. Thirteen parameters were selected to be tested as water quality indicators:

i) Temperature which depends on the intensity of heat stored in a volume of water (MELP 2002). Temperature changes affect the functioning of aquatic ecosystems and generally temperature affects the solubility of chemical compounds and also influences the effects of pollutant on aquatic life. Increase in temperature elevates the metabolic oxygen demand, and reduces oxygen solubility in the water which affects aquatic organisms and increases the toxicity of chemicals such as zinc, phenol and cyanide. On the other hand, human activities such as discharge of cooling water into water bodies, removal of riparian vegetation, and discharge of cold hypolimnion, affect water temperature ((NWQMS 2000; Dallas and Day 2004).

ii) Turbidity which causes light to be scattered and absorbed by suspended particles and molecules rather than to be transmitted in straight lines through a water column Turbidity, raised by sediments, algae and aquatic weeds, humic acid and other organic compounds resulting from decay of plants and leaves, reduces primary production by limiting light availability for photosynthesis and affects temperature sensitive species by reducing the water temperature as more heat is reflected at the water surface (EPA 2002; NWQMS 2000; Dallas and Day 2004). Therefore, since turbidity affects primary production and temperature sensitive species, it was measured using secchi disk depth to determine the water quality characteristics of the three dams and how the turbidity in the transferred water affects the water quality of Von Bach Dam.

iii) Dissolved oxygen, a measure of the amount of oxygen dissolved in the water is subject to diurnal and seasonal fluctuations caused by the variations in temperature. Its concentration depends on processes consuming and releasing it on a daily basis. For example respiration by aquatic plants consumes oxygen during the night while photosynthesis and physical transfer atmospheric processes release oxygen during the day (NWQMS 2000). Dissolved oxygen affects the solubility and availability of nutrients and thus the productivity of the aquatic ecosystem.

iv) pH, a measurement of hydrogen ion concentration in the water was also selected as an indicator of water quality because high pH facilitates the solubilization of ammonia, heavy metals and salts. High pH also encourages the precipitation of carbonate salts, while low pH increases the concentration of carbon dioxide and carbonic acid concentration. The lethal effect of pH on aquatic organisms occurs when the pH is below 4.5 and when it is above 9.5 (MELP 2002). Anthropogenic activities such as mining, agriculture, industrial effluents and acidic precipitation cause changes to pH.

v) Iron was selected as another water quality indicator because high concentration of iron points out the presence and decay of algae in a water body. The demand for iron in the water increases during algal blooms (NWQMS 2000). When the algae die, the iron is released back into the water column. Algae affect the aesthetic value of the water and are a concern to water treatment.

vi) Manganese was another indicator measured in this study to determine the effect of the changes on the water quality in Von Bach Dam due to water transfers and how these changes affect water treatment. Manganese is an essential micronutrient for aquatic plants and other organisms. When manganese is not present in sufficient quantities in the water, the photosynthetic process by aquatic plants is limited (Wetzel 1983). Like iron, high concentration of manganese in the water affects the aesthetic value of the water which is a concern to water treatment.

vii) Total phosphorus, a measure of both organic and inorganic forms of phosphorus is an essential nutrient for plant growth in freshwater systems and is often a limiting nutrient in water bodies and therefore its input can cause proliferations of algal growth (Wetzel 1983; NWQMS 2000; MELP 2002). It has been found out to be the main contributor to eutrophication in freshwater systems (Wetzel 1983; Kirke 2001). Major sources of total phosphorus are sewage treatment plant effluent, agriculture, urban development and industrial effluents. Therefore, it was measured in this study to determine the water quality characteristics of the three dams in terms of productivity and how water transfers and runoff from the catchment influence the eutrophication process in Von Bach Dam.

viii) Orthophosphate is a measure of the inorganic oxidized form of soluble phosphorus. This form of phosphorus is the most readily available for algal uptake during photosynthesis. High concentration of orthophosphate causes blooms of blue-green algae. Major sources of orthophosphate are sewage treatment plant effluent, agriculture, urban development and industrial effluents (Wetzel 1983; MELP 2002; Kirke 2001; Reynolds and Walsby 2008; Dallas and Day 2004). Orthophosphate was measured in this study to determine the water quality characteristic of the three dams in terms of productivity and to examine the effect of water transfers on the water quality of Von Bach Dam.

ix) Total nitrogen, a measure of all forms of nitrogen (organic and inorganic) is an essential plant nutrient and is often the limiting nutrient in marine systems. Major sources of total nitrogen are sewage treatment plant effluent, agriculture, urban development, paper plants, recreation, mining (blasting residuals), and industrial effluents (Wetzel 1983; NWQMS 2000; MELP 2002).

x) Ammonia is a measure of the most reduced inorganic form of nitrogen in water. Although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status water bodies (Wetzel 1983; MELP 2002; Dallas and Day 2004). Ammonia in excess concentration contributes to eutrophication which causes the growth of algae that affect water quality). Sources of ammonia are sewage treatment plant effluents, agriculture, urban development, paper plants, recreation, mining (blasting residuals), and industrial effluents (NWQMS 2000; Wetzel 1983; MELP 2002).

xi) Dissolved organic carbon is composed of humic substances and partly degraded plant and animal materials. It is a nutrient required for biological processes and when available in high concentration it lowers the dissolved oxygen concentration (MELP 2002). High dissolved organic carbon in water requires a higher dosage of chlorine which results in the production of a harmful byproduct called trihalomethanes.

xii) Chlorophyll *a* is a general indicator of plant biomass, because plants, algae, and cyanobacteria contain about 1–2 % chlorophyll *a*. A high concentration of chlorophyll *a* is a direct result of high nutrient input into the water. Measuring chlorophyll *a* in the water is a surrogate indicator of nutrient pollution (trophic status). Nutrients (total nitrogen and total phosphorus) may not indicate whether a water body has a nuisance algae problem, while an increase in chlorophyll *a* (chla) in water may indicate that plant, algae or cyanobacteria are actually growing ((MELP 2002; NWQMS 2000). Therefore, due to chlorophyll *a* being a good pollution indicator of nuisance blue-green algae, it was selected for measurement for this study.

xiii) Blue–green (Microcystis and Anabaena) were measured to determine the water quality characteristics in the three dams and the effects of water transfer on the water quality of Von Bach Dam because they are the most common blue green algae which cause nuisance bloom. Microcystis and Anabaena are very efficient utilizers of available nutrients and cannot usually be controlled by nutrient deprivation as they are able to fix nitrogen from the atmosphere and require only about 10 μg/l of phosphate to form a bloom (Kirke 2001). However, they are vulnerable to light limitation.

The six sampling sites established on the three dams included one on Swakoppoort Dam (SWK IT), one on Omatako Dam (OMT Pipe), and four locations on the Von Bach Dam (SL1–SL4) (Fig. 5.5). A Global Position System (GPS) was used in the establishment of the sampling locations. Single locations were established on Swakoppoort Dam and Omatako Dam in order to determine the water quality characteristics transferred to Von Bach Dam. In Von Bach Dam, sampling location SL1, was at the point where water from Swakoppoort Dam is discharged, SL2 and SL3 where established in the middle of the dam to determine the spatial variation in the water quality due to water transfers, and SL4 was at the intake point where water transferred from Omatako Dam is discharged into Von Bach Dam which is also the point where runoff from the catchment area flows into Von Bach Dam.

Water samples were collected on a weekly basis from the three dams; two weeks in a month on Von Bach Dam and Omatako Dam and one week in a month on Swakoppoort Dam. The differences in sampling frequency were dictated by the distance between the dams. This was cost-effective for the study and it was in line with the existing sampling program used by the managing company, NAM-WATER. A dip sampling method involving the dipping of the sampler into the water to retrieve the water sample which is transferred to the appropriate sample container was chosen in line with recommendations made in Burns et al. (2000).

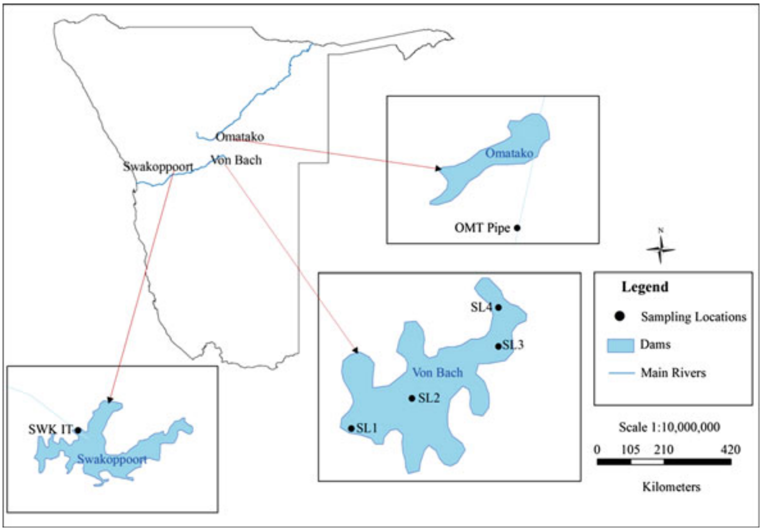

Fig. 5.5 Water sampling sites in the study area *OMT pipe* Omatako pipe; *SWK IT* Swakoppoort intake tower; *SL* Sampling Site

The interview method was used to collect information on the effects of water transfers on water treatment. A checklist was used to collect data on the volume of water transferred from Swakoppoort and Omatako Dams into Von Bach Dam and the volume of water abstracted to the treatment plant.

Descriptive statistics were used to analyze the collected data on each parameter. The mean and standard deviation values were used to determine the elevation of each water quality parameter among the three dams. A two way-ANOVA at a 5 % significance level was carried out to determine the statistically significant difference in each water quality parameter of the three dams. Box plots were generated for each water quality parameter at the four sampling locations of Von Bach Dam to show the influence by water transfers. A one way-ANOVA was carried out to determine the statistically significant difference of each water quality parameter between sampling locations. Correlation coefficient I between water volume transferred from Swakoppoort and Omatako Dams into Von Bach Dam and the water quality parameters at SL1 and SL4 of Von Bach Dam was determined. The correlation was done to determine the influence of water volume transferred into Von Bach Dam on the water quality parameters at SL1 and SL4. Additionally, the correlation coefficient I was also determined between the water quality parameters of Swakoppoort, Omatako and Von Bach Dams to determine the influence of water transfers on the water quality of Von Bach Dam.

The results of the analyzed water quality parameters are presented in Figs. 5.6 through 5.20.

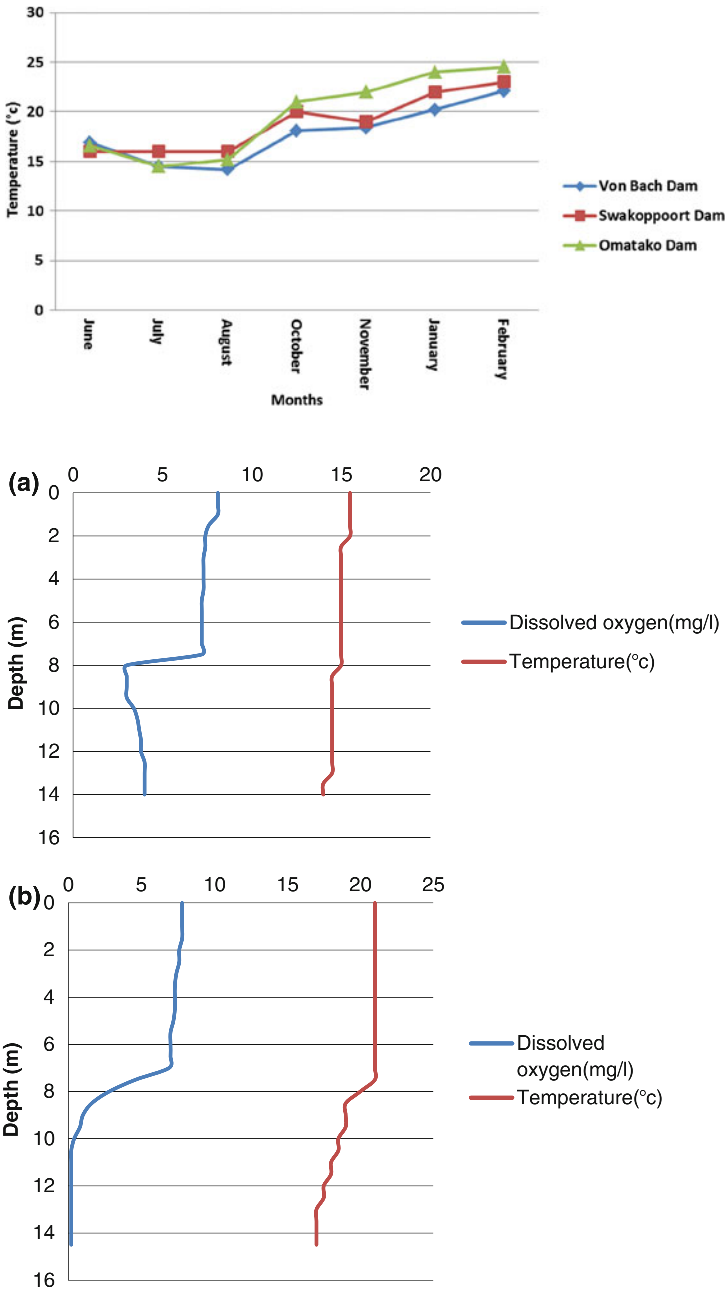

Fig. 5.6 Water temperature of the three dams (June 2010–February 2011) **a** No thermal stratification in Swakoppoort Dam in July 2010, **b** thermal stratification in Swakoppoort Dam in October 2010, **c** no thermal stratification in Von Bach Dam in July 2010, **d** thermal stratification in Von Bach Dam in October 2010

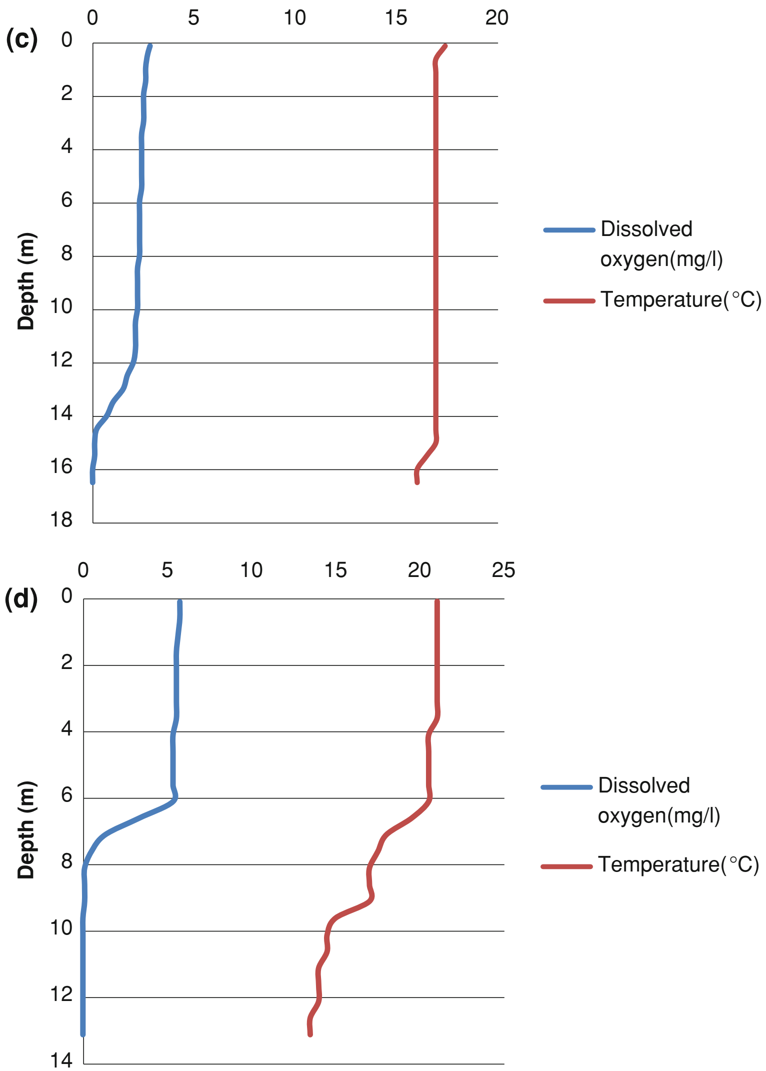

Fig. 5.6 continued

Temperature

The water temperature in Swakoppoort, Omatako and Von Bach Dams was low in June, July and August (Fig. 5.6). The water temperature of the three dams increased from August till February 2011. The mean temperature of Swakoppoort Dam was 18.9 °C, with a standard deviation of 3.0 °C and $n = 7$; Von Bach Dam was 17.8 °C, with a standard deviation of 2.9 °C and $n = 7$, and Omatako Dam was 19.7 °C, with a standard deviation of 4.2 °C and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.500$) in the temperature of the three dams at 5 % significance level. Swakoppoort Dam water stratification diminished (i.e. no thermocline) in July 2010 (Fig. 5.6a) and in October 2010 the stratification developed (i.e. with a thermocline at 7.5 m) (Fig. 5.6b).

There was no stratification of water in Von Bach Dam (i.e.no thermocline) in July 2010 (Fig. 5.6c) and in October 2010 the stratification developed (i.e. with a thermocline at 6 m) (Fig. 5.6d).

Turbidity

The secchi disk depths of Von Bach Dam were greater than these of Swakoppoort Dam, except in January and February 2011 (Fig. 5.7). The mean secchi disk depths were: Von Bach Dam 1.5 m with a standard deviation of 0.9 m and $n = 7$; Swakoppoort Dam 0.5 m with a standard deviation of 0.4 m and $n = 7$, and Omatako Dam was 0.2 m with a standard deviation of 0.15 m. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p = 0.016$) in the secchi disk depths of the three dams at 5 % significance level.

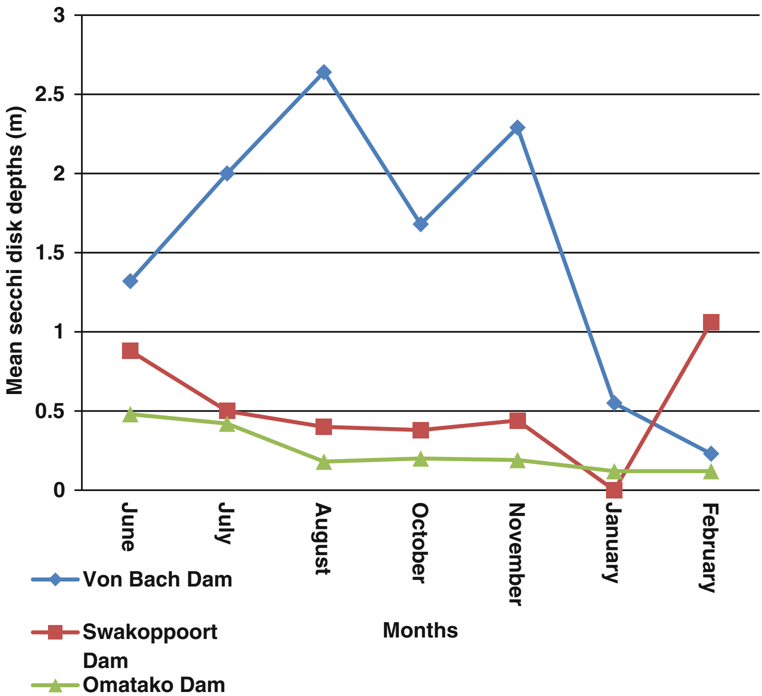

Fig. 5.7 Secchi disk depths of the three dams (June 2010–February 2011)

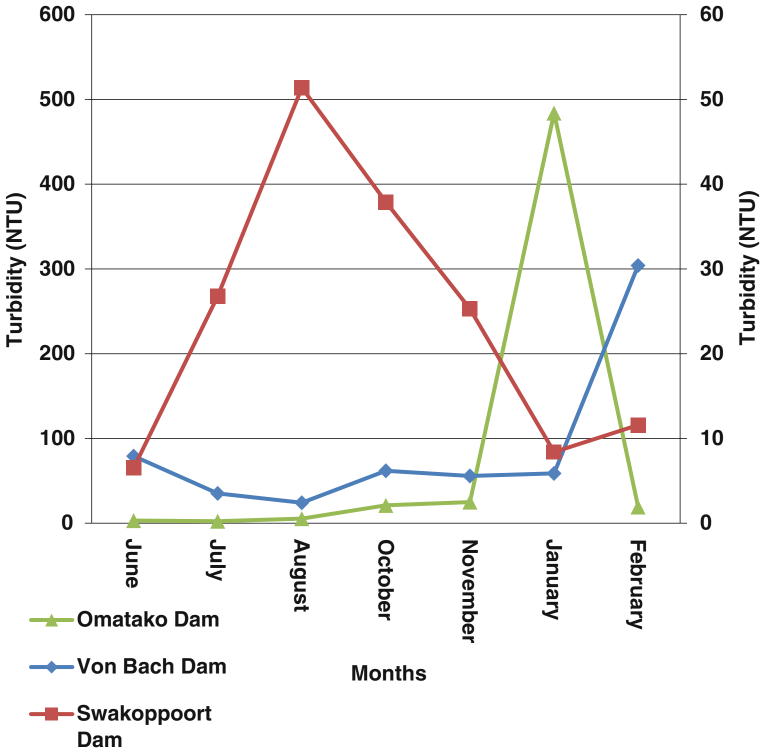

Fig. 5.8 Turbidity of the three dams (June 2010–February 2011)

The turbidity of the water in Von Bach Dam remained fairly stable between June and December 2010; it increased between January and February 2011 (Fig. 5.8). The turbidity of water in Swakoppoort Dam was highest in August 2010 while Omatako Dam was highest in January 2011 Omatako Dam had a mean turbidity of 80.1NTU with a standard deviation of 178.4NTU and $n = 7$, while Swakoppoort Dam had a mean turbidity of 24.0NTU with a standard deviation of 16.6NTU and $n = 7$, and Von Bach Dam had a mean turbidity of 8.9NTU with a standard deviation of 9.7NTU and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.417$) in the turbidity of water in the three dams at 5 % significance level.

Dissolved Oxygen

The dissolved oxygen concentration of Swakoppoort Dam, Von Bach Dam and Omatako Dam displayed a reverse pattern as compared to temperature pattern. The dissolved oxygen of the three dams was highest in July and began to drop in

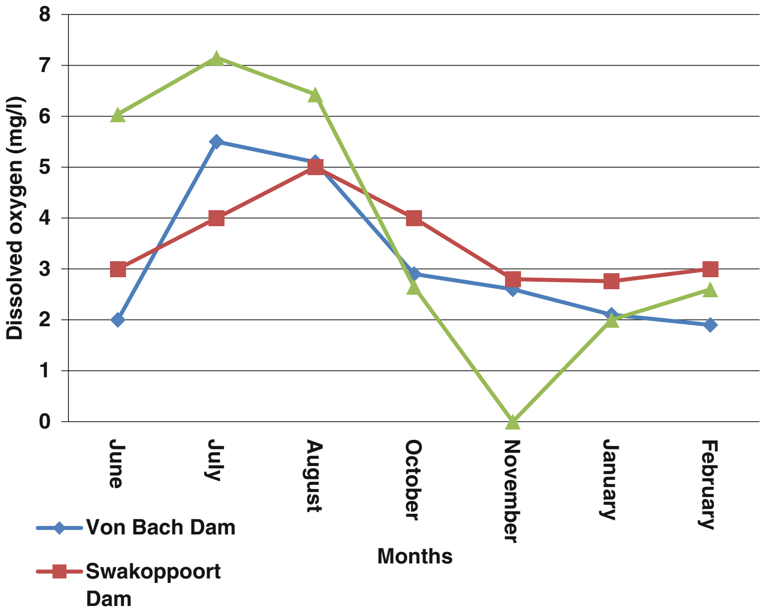

Fig. 5.9 Dissolved Oxygen of Von Bach and Swakoppoort Dams (June 2010 – February 2011)

August (Fig. 5.9). The mean dissolved oxygen values of the three dams were: Swakoppoort Dam 3.5 mg/l with a standard deviation of 0.9 mg/l and $n = 7$; Von Bach Dam was 3.2 mg/l with a standard deviation of 1.5 mg/l and $n = 7$ and Omatako Dam was 3.84 mg/l with a standard deviation of 2.70 mg/l. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.601$) in the dissolved oxygen of the three dams at 5 % significance level.

Iron

The iron concentration in Von Bach and Omatako dams was fairly stable from June 2010 to November 2010). The iron concentration in the water of Swakoppoort and Omatako Dams was high in January 2011 (Fig. 5.10). The mean iron concentrations in the three dam were: Omatako Dam 1.2 mg/l with a standard deviation of 2.1 mg/l and $n = 7$; Swakoppoort Dam 0.0 mg/l with a standard deviation of 0.2 mg/l and $n = 7$; Von Bach Dam 0.3 mg/l with a standard deviation of 0.4 mg/l and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.199$) in the iron of the three dams at 5 % significance level.

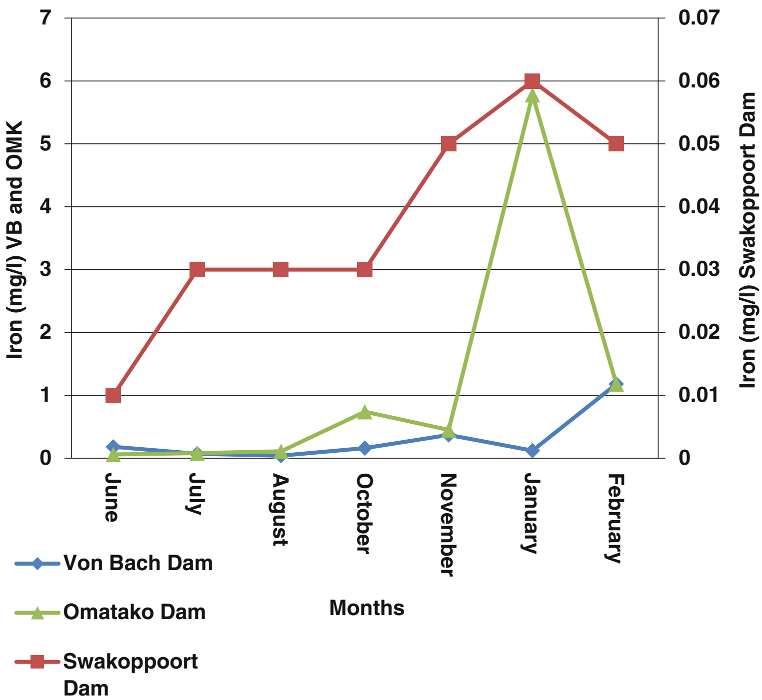

Fig. 5.10 Iron concentration of the three dams (June 2010–February 2011)

Manganese

Manganese concentration was higher in Von Bach Dam than in Swakoppoort Dam water in June, November and February while in Omatako Dam, an increase in the manganese concentration was observed in February (Fig. 5.11). The mean manganese of the three dams were: Omatako Dam 0.1 mg/l with a standard deviation of 0.1 mg/l; Swakoppoort Dam was 0.1 mg/l with a standard deviation of 0.0 mg/l; Von Bach Dam was 0.1 mg/l with a standard deviation of 0.1 mg/l. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.301$) in the manganese of the three dams at 5 % significance level.

pH

The water pH in Von Bach Dam and Swakoppoort Dam was following a similar pattern, increasing from June till October. There was a decrease in November to January in Swakoppoort and Omatako Dams (Fig. 5.12). The mean pH of Omatako Dam water was 8.2 with a standard deviation of 0.7 and $n = 7$; Swakoppoort

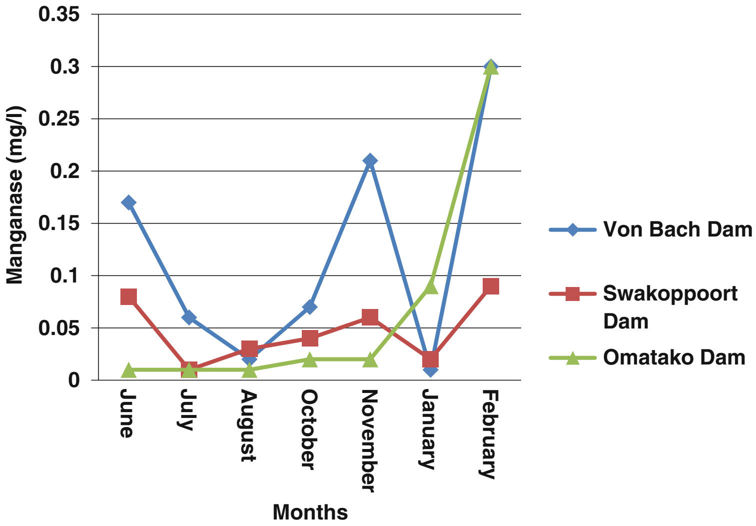

Fig. 5.11 Manganese concentration of the three dams (June 2010–February 2011)

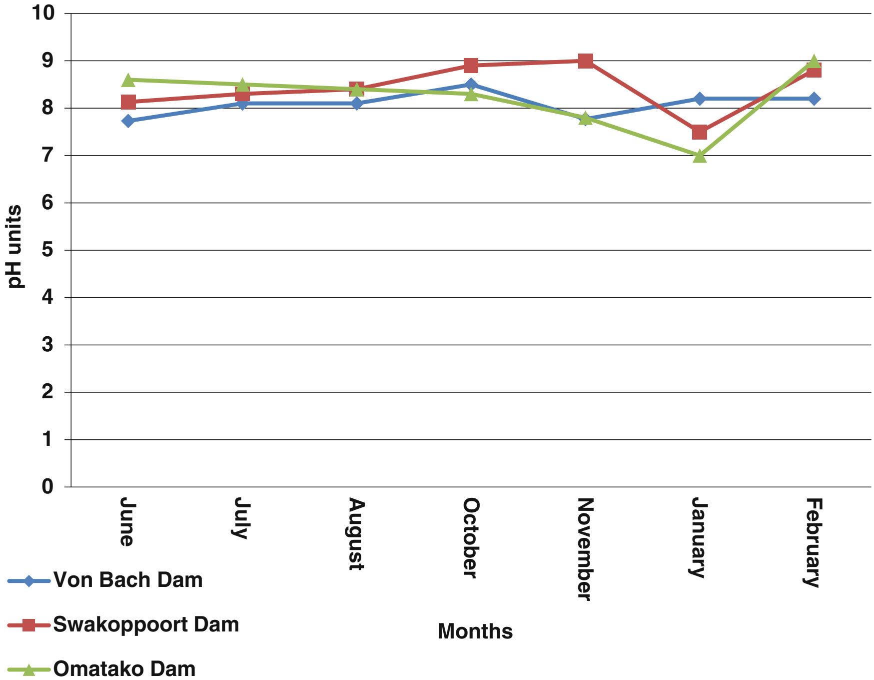

Fig. 5.12 pH of the three dams (June 2010–February 2011)

Dam mean pH was 8.4 with a standard deviation of 0.5 and $n = 7$ and Von Bach Dam mean pH was 8.1 with a standard deviation of 0.3 and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.452$) in the pH of the three dams at 5 % significance level.

Total Phosphorus

The mean total phosphorus was highest in Swakoppoort Dam and lowest in Von Bach and Omatako Dams in July. From January to February an increase in total phosphorus was observed in Swakoppoort Dam, and slightly in Von Bach Dam. Total phosphorus in Omatako was high in January and dropped drastically in February (Fig. 5.13). The mean total phosphorus in the three dams were: Swakoppoort Dam 0.3 mg/l, with a standard deviation of 0.1 mg/l and $n = 7$; Omatako Dam 0.1 mg/l with a standard deviation of 0.2 mg/l and $n = 7$ and Von Bach Dam was 0.1 mg/l with a standard deviation of 0.0 mg/l and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p = 0.010$) in the total phosphorus of the three dams at 5 % significance level.

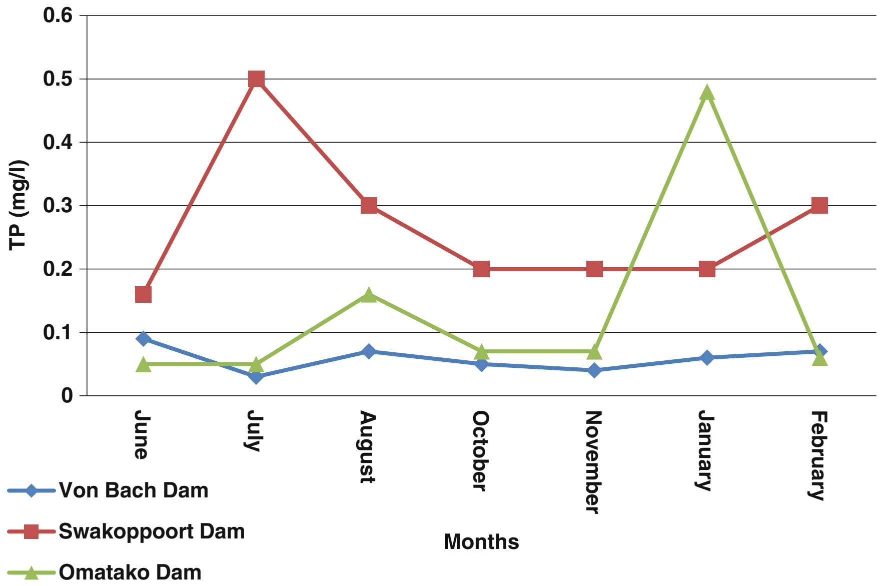

Fig. 5.13 Total phosphorus of the three dams (June 2010–February 2011)

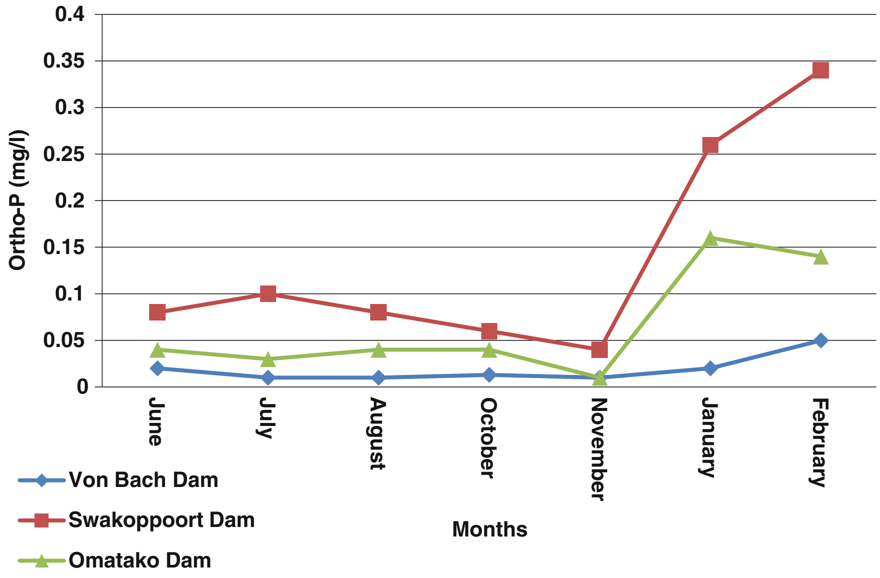

Fig. 5.14 Orthophosphate of the three dams from June 2010 to February 2011

Orthophosphate (PO_4^{-3})

Orthophosphate was fairly stable in the three dams from June to October, and started to increase from November in Swakoppoort and Omatako Dams (Fig. 5.14). The mean orthophosphate in the three dams were: Swakoppoort Dam 0.1 mg/l, with a standard deviation of 0.1 mg/l and $n = 7$; Omatako Dam 0.1 mg/l with a standard deviation of 0.1 mg/l and $n = 7$ and Von Bach Dam was 0.0 mg/l with a standard deviation of 0.0 mg/l and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p = 0.028$) in the orthophosphate of the three dams at 5 % significance level. Using the minimum and maximum values (Appendix 5.1) of the measured orthophosphate concentration of the three dams, it shows that they are all in a eutrophic state with the range of orthophosphate between 0.025 to 0.25 mg/l (DWA 1996).

Total Nitrogen

The total nitrogen concentration was fairly stable from June to November in all the three dams In January an increase in total nitrogen was observed in all the three dams, with the highest concentration in Von Bach Dam, followed by Omatako Dam and Swakoppoort Dam (Fig. 5.15). The mean total nitrogen of Von Bach Dam was 2.5 mg/l with a standard deviation of 3.2 mg/l and $n = 7$, Swakoppoort

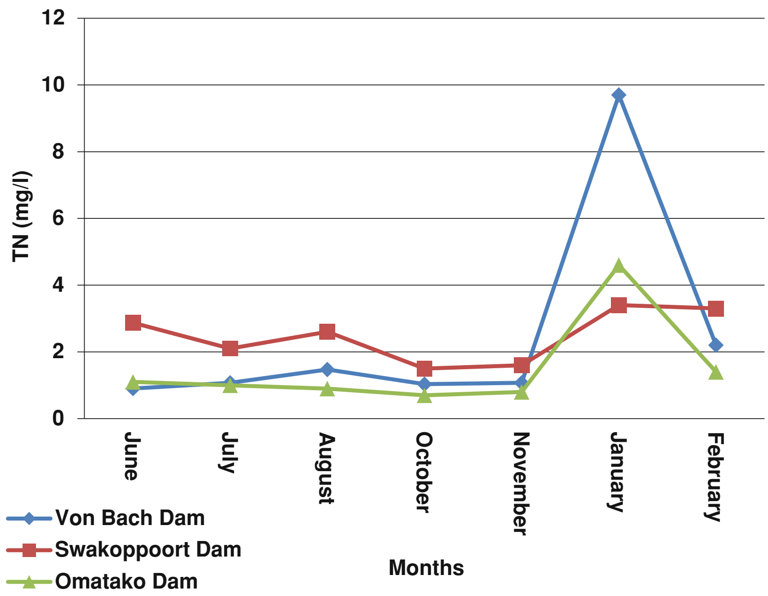

Fig. 5.15 Total nitrogen of the three dams (June 2010–February 2011)

Dam was 2.5 mg/l with a standard deviation of 0.77 mg/l and $n = 7$ and Omatako Dam was 1.5 mg/l with a standard deviation of 1.4 mg/l and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant differences ($p = 0.597$) in the total nitrogen of the three dams at 5 % significance level.

Ammonia (NH_4-N)

Ammonia (NH_4–N) concentration was the highest in Von Bach and Swakoppoort Dams in June, July, August, January and February compared to Omatako Dam (Fig. 5.16). The mean ammonia (NH_4–N) of Von Bach Dam was 0.3 mg/l with a standard deviation of 0.1 mg/l and $n = 7$, Swakoppoort Dam was 0.4 mg/l with a standard deviation of 0.2 mg/l and $n = 7$ and Omatako Dam was 0.0 mg/l with a standard deviation of 0.0 mg/l and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p = 0.02$) in the ammonia of the three dams at 5 % significance level. The ammonia (NH_4–N) concentration (minimum and maximum value) of the three dams was within the Target Water Quality Range (TWQR) of 7 mg/l for an aquatic ecosystem (DWA 1996).

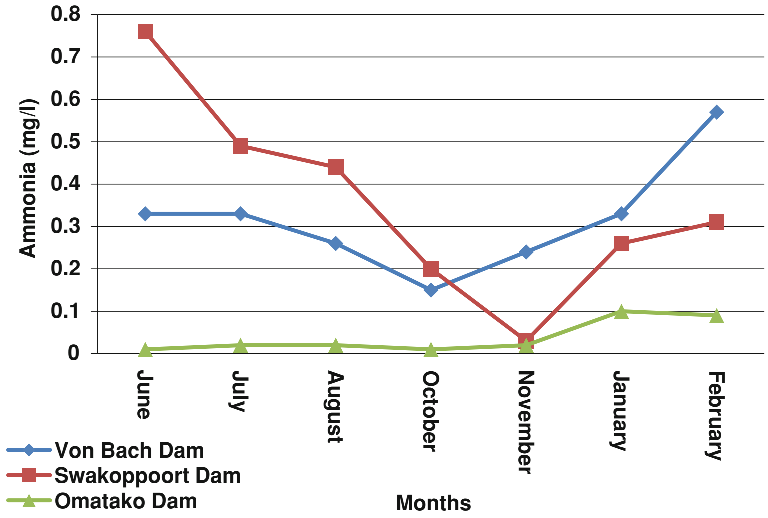

Fig. 5.16 Ammonia (NH_4–N) level of the three dams (June 2010–February 2011)

Dissolved Organic Carbon

The dissolved organic carbon was higher in Swakoppoort Dam than in Von Bach and Omatako Dams from June to February (Fig. 5.17). The mean dissolved organic carbon of Swakoppoort Dam was 10.8 mg/l with a standard deviation of 1.8 µg/l and $n = 7$, while Von Bach Dam was 5.5 mg/l with a standard deviation of 0.4 µg/l and $n = 7$, and Omatako Dam was 5.2 mg/l with a standard deviation of 1.1 µg/l and $n = 7$. Statistical analysis of the data, carried out using a two way-ANOVA, showed a significant difference ($p = 0.00$) in the dissolved organic carbon of the three dams at 5 % significance level.

Chlorophyll a

The chlorophyll *a* concentration was higher in Swakoppoort Dam, than in Von Bach Dam and Omatako Dam in July. Chlorophyll *a* was mainly stable in Von Bach and Omatako Dams from July to February (Fig. 5.18). The mean chlorophyll *a* value of the three dams were: Swakoppoort Dam 88.2 µg/l with a standard deviation of 79.8 µg/l and $n = 7$; Von Bach Dam 6.4 µg/l with a standard deviation of 5.9 µg/l and $n = 7$; Omatako Dam was 3.7 µg/l with a standard deviation of 6.0 µg/l and $n = 7$. Statistical analysis of the data, carried out using a two way-ANOVA, showed a significant difference ($p = 0.004$) in the chlorophyll *a* of the three dams at 5 % significance level.

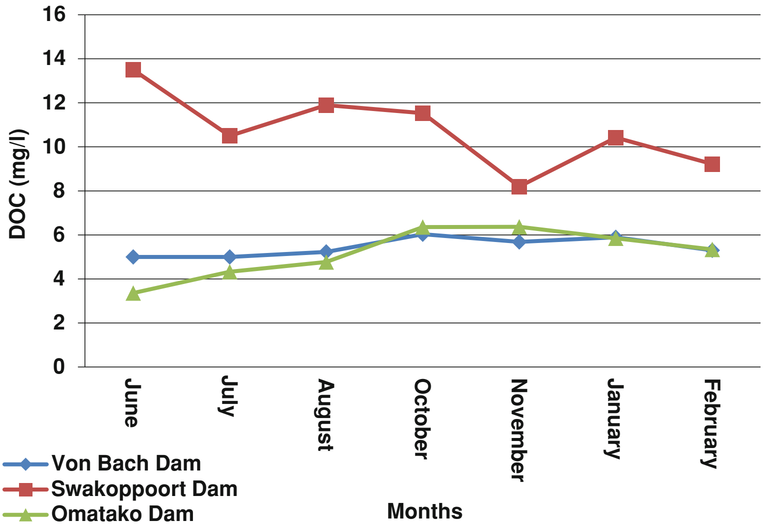

Fig. 5.17 Dissolved organic carbon of the three dams from June 2010 to February 2011

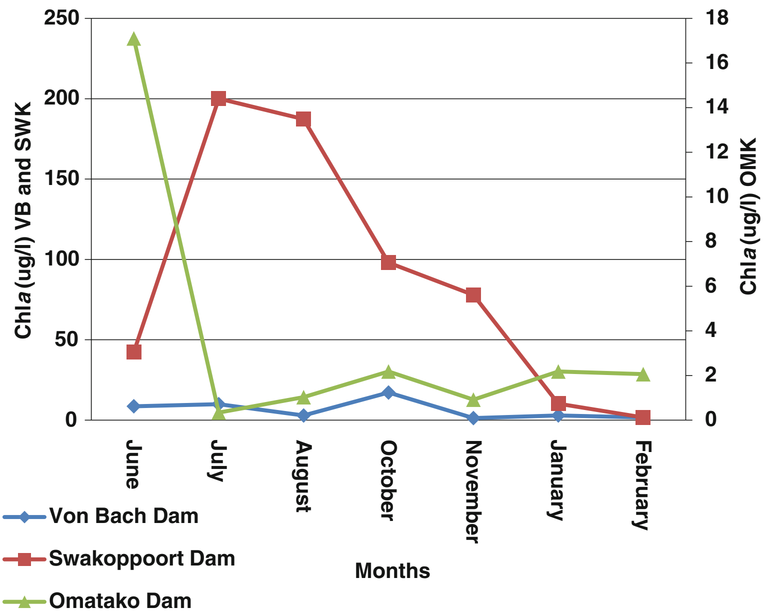

Fig. 5.18 Chlorophyll *a* levels at the three dams (June 2010–February 2011)

Anabaena

Anabaena cells counts were not found in Omatako Dam water from June to February, but they were found in Swakoppoort and Von Bach Dams (Fig. 5.19). In November, anabaena was higher in the water of Swakoppoort Dam and in the Von Bach Dam water it was higher in February. The mean anabaena of Swakoppoort Dam was 7722.1 count/ml, with a standard deviation of 8481.0 count/ml and $n = 7$; while in Von Bach Dam the mean anabaena was 2852.8 count/ml, with a standard deviation of 5912.2 count/ml and $n = 7$, and in Omatako the mean anabaena was 0.0 count/ml, with a standard deviation of 0.0 count/ml and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed no significant difference ($p = 0.075$) in the anabaena algae of the three dams at 5 % significance level.

Microcystis

Microcystis cells were the highest in Swakoppoort Dam water, few were found in Von Bach Dam water and none in Omatako Dam water (Fig. 5.20). The mean number of mycrocystis cells at Swakoppoort Dam was 194866.39 count/ml, with a standard deviation of 2.01 count/ml and $n = 7$, while the Von Bach Dam mean mycrocystis was 1447.1 count/ml, with a standard deviation of 2821.6 count/ml and $n = 7$, and the Omatako Dam mean microcystis was 0.0 count/ml, with a standard deviation of 0.0 count/ml and $n = 7$. Statistical analysis of the data, carried out using two way-ANOVA, showed a significant difference ($p = 0.007$) in the microcystis of the three dams at 5 % significance level.

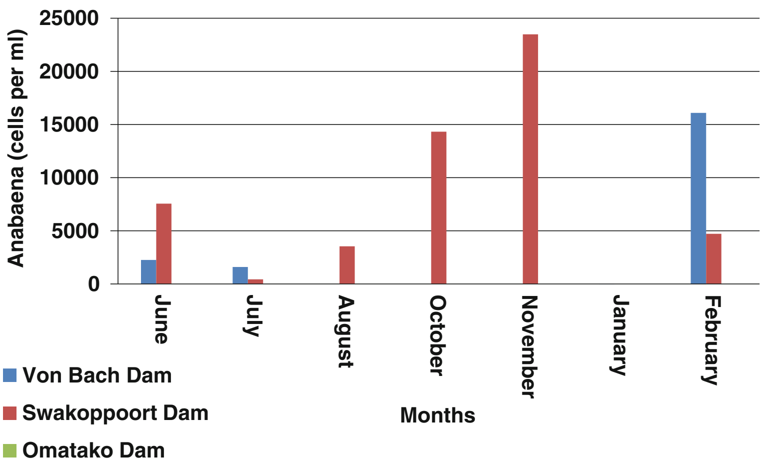

Fig. 5.19 Anabaena of the three dams (June 2010–February 2011)

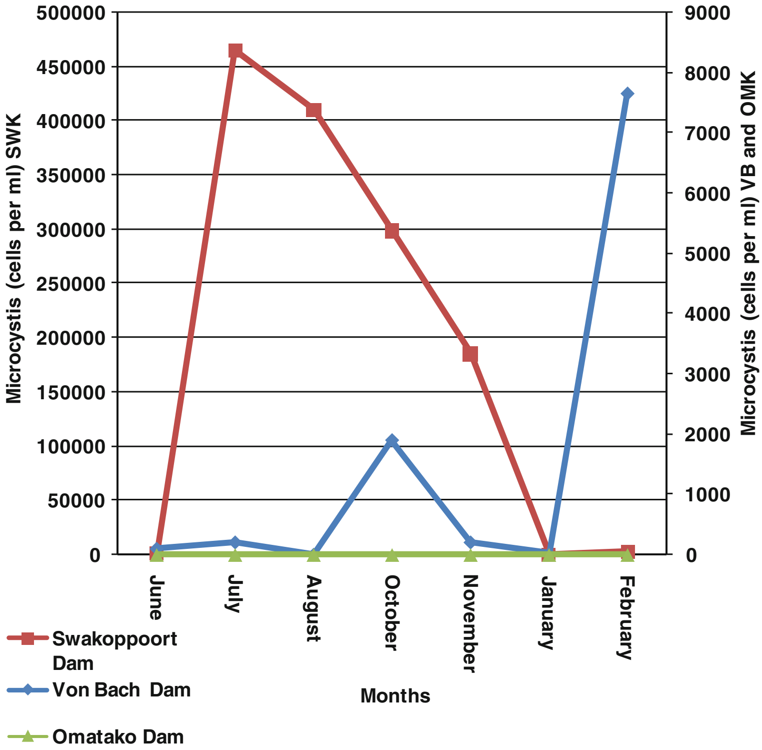

Fig. 5.20 Microcystis levels at the three dams (June 2010–February 2011)

Discussion

Secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a* and microcystis were not the same in the three dams. Elevation in the water quality parameters of the three dams were linked to land use activities in their catchment areas, land covers of their catchment areas, geology of their catchment areas, and the stratification of the water bodies. However, the water temperature of the three dams was statistically similar during all the months. The temperature of the water among the three dams ranged from 14 °C during the winter months (June–July) and 24 °C during the summer months (November 2010–February 2011). Compared to other water bodies in neighboring South Africa, it becomes evident that the temperatures were more or less similar to those of the three Lakes in Namibia. For example, Lake Midmar, South Africa, was found to have a minimum water temperature of 12 °C during July and a maximum water temperature of 26 °C during November and December (Breen 1983). The three lakes maintained higher dissolved oxygen in June and July than in November-February. While it is documented that tropical lakes of moderate to great depths are warm, monomictic and show great consistency in seasonal mixing the three dams displayed monomictic characteristics be as they stratify once a year like temperate lake which are normally cold, polymictic and dimictic (Lewis 1996; Kirillin 2010).

The turbidity of Von Bach Dam ranged from 2.4 to 30.4NTU, Swakoppoort Dam ranged from 6.5 to 51.4NTU, and Omatako Dam ranged from 2.4 to 484NTU. Von Bach Dam had highly turbid water in January and February which was caused by highly turbid runoff from the catchment area and turbid water I from Omatako Dam. The high turbidity in the water from Omatako Dam was due to the geology of its catchment area which is made up of sand and calcrete. The shallowness of the dam (11 m) and the high evaporation losses also contributes to the increase in turbidity of the water of Omatako Dam. Generally, in shallow lakes turbidity is caused by sediment re-suspension while in deeper lakes turbidity is caused by chlorophyll *a* (Jackson 2003). The turbidity in the water of Swakoppoort Dam was caused by algal bloom occurrence dominated by microcystis in July. Algal bloom is known to increase water turbidity as they insistently flow with the water in any direction (Scheffer 2004).

The high turbidity of Swakoppoort Dam was measured at the abstraction tower which has a high concentration of algae scum. Algae are pushed by wind to the shoreline of lake and the movement is also controlled by the buoyancy level (Reynolds and Walsby 2008). Land use activities such as crop cultivation and cattle and game farming, and poor land cover in the catchment area expose top soil to water erosion which gets carried away to be deposited into the water bodies thus raising water turbidity (Li et al. 2009). Industries, game and cattle farming in the catchment of Swakoppoort Dam must have contributed to the turbidity at the inflow point, even though no water samples were collected from this point. The high chlorophyll *a* concentration recorded in Swakoppoort Dam also contributed to the high water turbidity in the dam.

Commonly, thermal stratification of water is destroyed during a period of lower temperature (Breen, 1983; Wetzel 1983; Hart and Allanson 1984). During thermal stratification (i.e. anoxic conditions), manganese, orthophosphate, ammonia and iron which is trapped in the sediment is released into underlying water (Wetzel 1983). When the thermal stratification breaks, manganese, ammonia, orthophosphate and iron are released to the water column (Wetzel 1983; Breen 1983; Hart and Allanson 1984; Rast and Thornton 1996). These facts explain the high manganese concentration in July when the thermal stratification broke in Swakoppoort Dam. But the increase in the manganese concentration of Swakoppoort Dam in November and February could be due to runoff from the catchment area containing organic matter while the increase in the manganese concentration in Von Bach Dam during November and February could be due to water transfers and runoff from the catchment area. Runoff contains organic matter and humic substances which are sources of manganese (Wetzel 1983). The measured manganese concentration of the three dams were within the Target Water Quality Range (TWQR) for an aquatic ecosystem of 0.2 mg/l which is below the Chronic Effect Value of 0.4 mg/l (DWA 1996).

Iron concentration in the water of Swakoppoort Dam increased from June 2010 to February 2011. The increase could be due to the iron released from the sediment (Hongve 1997; Davison 1993). Swakoppoort Dam had the highest concentration of dissolved organic carbon, which could be due to the decaying of organic matter in the dam from dead plants and algae, and those supplied by runoff from the catchment area. In some studies, dissolved organic carbon was found to increase in the water due to land use, rising temperature, rainfall, and acid deposition (Evans et al. 2004). These factors where not established in this study. The concentration of dissolved organic carbon in Swakoppoort Dam water was between 8.2 and 13.5 mg/l. It shows that the iron concentration in the dam was too high for the Von Bach treatment plant to lower to below 4 mg/l to meet the Windhoek aquifer artificial recharge requirement.

It has been documented that degradation of water quality is faster in tropical lakes than in temperate lakes due to strong nutrient cycling during thermal stratification (Lewis 2000) and that total phosphorus in lakes originates from the catchment in many studies (Breen 1983; Wetzel 1983; Hart and Allanson 1984; Søendergaard et al. 2000). For example, in Southland, New Zealand, the increase in total phosphorus in the stream was caused by a dairy farm in its catchment (Monaghan et al. 2007); in the catchment of Lake Chivero, Zimbabwe, the load of total phosphorus was found to be higher from the sub-catchment containing home industries than from the sub-catchment containing residential areas (Mvungi et al. 2003). Similarly, it has been confirmed that tributaries of Pao-Cachinche reservoir, Venezuela, introduced high orthophosphate, total phosphorus and ammonia from domestic wastewater, and from poultry and pig farms (Gonzalez et al. 2004). Therefore, in the case of the three dams whose catchments lacking large scale industrial and dense settlements with the exception of Swakoppoort Dam catchment which has modest industries and low density residential areas, the high concentration of total phosphorus and orthophosphate could originate from sediment deposits. Total phosphorus was higher in July (0.5 mg/l), which is the period when the dam had an algal bloom, but orthophosphate was very low (0.1 mg/l). In January and February when Swakoppoort Dam received a high runoff from the catchment area, orthophosphate increased in the water and this could be linked to the external supply from the catchment area and also from the sediment re-suspension. Similarly, the increase in total phosphorus in the Omatako Dam in January could be due to the external input from the catchment area. Land use activities in the two catchment areas such as industry, sewage ponds, game and cattle farming, and subsistence crop cultivation contributed to increased loads of phosphorus in the two dams (Kitaka et al. 2002; Rahman and Bakri n.d; Schindler 2006).

Swakoppoort Dam had a bloom of blue-green algae in June 2010, which was dominated by microcystis algae. This was similar to the Lake Victoria bloom of 1986, which was also dominated by microcystis algae (Ochumba and Kibaara 2008) and that of Nhlanganzwane Dam, South Africa which also had a bloom of blue-green algae in 2007 dominated by microcystis algae and which produced microcystin followed by the bio-intoxication of wild animals (Oberholster et al. 2009).

While the bloom in Swakoppoort dam did not affect any wild animals or cattle, water quality for human consumption was affected; the water could not be treated and as such water transfer to Von Bach Dam was delayed (Kirke 2001; Oberholster et al. 2009).

Ammonia concentration in Von Bach Dam and Swakoppoort dams displayed similar pattern; very high when the dam water was completely mixed in June and also high during the period when runoff from the catchment area reached the dams. However, the ammonia concentrations in the two dams were within the Target Water Quality Range for an aquatic ecosystem as prescribed in the South African Water Quality Guideline for Aquatic Ecosystems.

Effects of Water Transfers

In many cases inter-basin water transfers are done for water supply augmentation and for improvement of water quality. The transfer of water for water supply augmentation could affect water quality in the recipient dam. In the case of the three dams under study, temperature, turbidity, dissolved oxygen; iron, manganese, pH, total nitrogen, and anabaena were statistically and significantly similar in the three dams. The water quality parameters which were not statistically and significantly similar in the three dams were: Secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a* and microcystis. In terms of productivity (i.e. nutrients enriched), the results showed that, the three dams are not similar. Swakoppoort is the most productive among the three dams. Therefore, since some water quality parameters were not similar among the three dams, transferring water from one to the other is likely to increase concentration of some parameters which would affect water quality and water treatment costs.

The sampling of runoff from the catchment area was done only once due to the unpredictability of the occurrence of river flows on an ephemeral river. Thus the results may not be a total reflection of the situation but it gives an indication of the water quality from the catchment area. It is also important to note that the transfer of water from Swakoppoort and Omatako Dams and runoff from the catchment area occurred simultaneously and therefore it was not easy to separate their individual effects on the water quality of Von Bach Dam. However, most of the inflow into Von Bach dam originated from the catchment area given the fact that out of the 24.3 Mm^3 received by the dam, 8 Mm^3 was transferred from Omatako dam and only 3 Mm^3 from Swakopproot dam (Figs. 5.21, 5.22 and 5.23). Thus the catchment contributed about 12.9 Mm^3.

It is worthwhile to point out that during the time of this research; about 23 Mm^3 was abstracted from Von Bach Dam and transmitted to meet Windhoek water supply demand. It is also worthwhile to note that Von Bach storage decreased appreciably between April and December 2010. Therefore, it becomes evident that

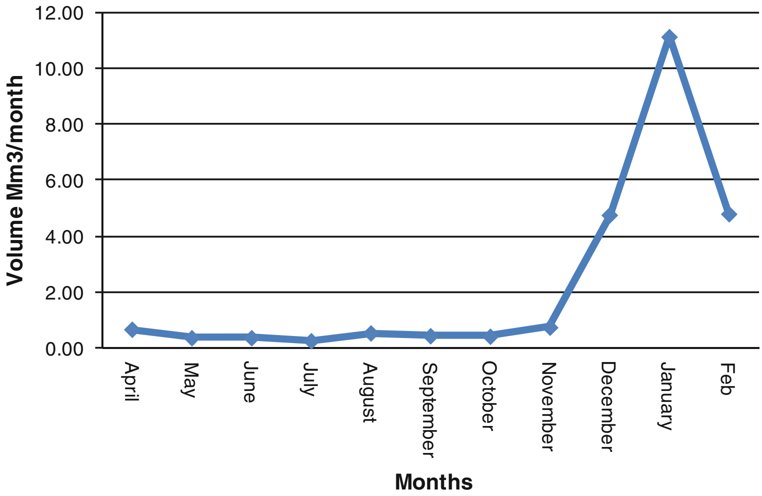

Fig. 5.21 Total water volume flowing into Von Bach Dam (April 2010–February 2011) *Mm*^{3} millions cubic meters*; data source* NamWater Hydrology Unit

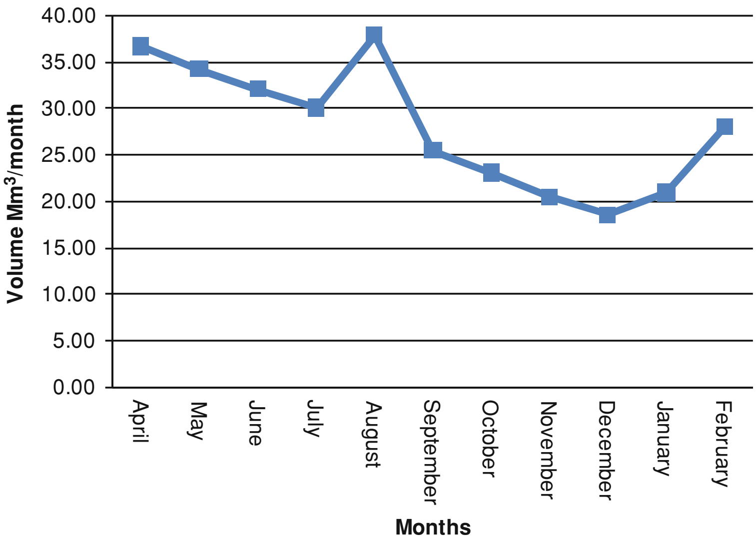

Fig. 5.22 Volume of water stored in Von Bach Dam (April 2010–February 2011) *Mm*^{3} millions cubic meters*; data source* NamWater Hydrology Unit

without augmentation of water through water transfers Von Bach Dam could easily be depleted completely if it relied only on runoff from the catchment area given the high abstraction rates to meet water demand for Windhoek city.

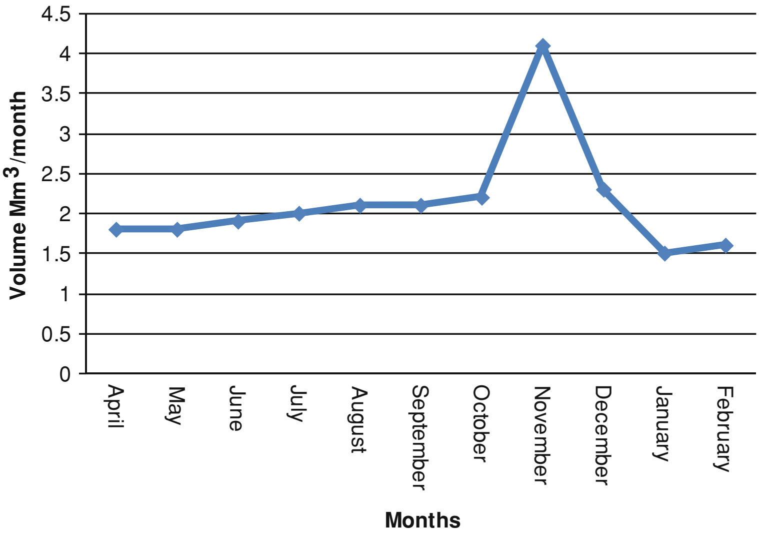

Fig. 5.23 Volume of water abstracted from Von Bach Dam and conveyed to the treatment plant (April 2010–February 2011) *Mm*^{3} millions cubic meters; *data source* NamWater Hydrology Unit

Conclusions

The results of the secchi disk depths, turbidity, dissolved oxygen; iron, total phosphorus, ammonia (NH_4–N) and chlorophyll *a* indicated that there were significant effects resulting from the water transfers. The influence of water transfers on water quality of Von Bach dam was localized at the discharge points SL4 (the inflow of Von Bach Dam) and SL1 (the outflow of Von Bach Dam) and problems experienced in water treatment were partly due to high ammonia, high dissolved organic carbon and high turbidity arising from water transfers from the other two dams and partly due to runoff from Von Bach dam catchment area.

The three dams are statistically similar with respect to water temperature, pH and dissolved oxygen. High turbidity was observed in Von Bach Dam during periods of natural inflows from the upstream catchment area and water transfers from Omatako Dam. In Swakoppoort Dam, high turbidity was observed when algal blooms occurred. Among the three dams Swakoppoort Dam was found to be nutrient-rich, particularly in total phosphorus and orthophosphate. The nutrients resulted in a bloom of blue-green algae which delayed water transfers to Von Bach Dam. The bloom was dominated by microcystis algae. Furthermore within the three dams, secchi disk depths, total phosphorus, orthophosphate, ammonia, dissolved organic carbon, chlorophyll *a*, and microcystis algae were statistically different.

During water transfers and inflow of runoff from the upstream catchment into Von Bach Dam, secchi disk depths, turbidity, dissolved oxygen, iron; total phosphorus, ammonia and chlorophyll *a* were not statistically different at the four sampling locations, indicating no major influence by water transferred from Swakoppoort and Omatako Dams, and runoff from the catchment area. Furthermore, iron and turbidity at the discharge points SL1 and SL4 correlated with the volume of water transferred from Swakoppoort and Omatako Dams, indicating the influence of water transfers on these parameters. Thus the effect of water transfers and runoff from the catchment on Von Bach Dam water was localized. At the Von Bach treatment plant, high turbidity, dissolved organic carbon, and ammonia (NH_4–N) resulted from water transfers and runoff from the catchment area presented problem for water treatment.

Recommendations

Monitoring the effect of water transfer from Swakoppoort Dam, Omatako Dam and runoff from the catchment should continue and should be repeated for 5 years to determine any water quality changes in Von Bach Dam.

To reduce the increase in turbidity of the Von Bach Dam water caused by water transferred from Omatako Dam and runoff from the catchment, filtration structures such as gabions should be installed at the inlet of Von Bach Dam to filter debris, humic substances, suspended solids and organic matter before the water flows into the dam. Reducing the inflow of these substances will also minimize the concentration of dissolved organic carbon and ammonia in the water which are released during the decomposition of these elements.

The treatment plant should prepare for high turbidity, manganese, iron, ammonia, and dissolved organic carbon in the water during water transfer periods and runoff from the catchment. To ensure a sustainable good water quality at Von Bach Dam without a severe effect on water treatment in the future, the water quality of the three dams should be managed in an integrated manner. Pollution sources need to be identified in all the catchment areas and should be monitored to determine their effect on the water quality in the dams. Catchment management strategy or measures of land uses activities, cattle and game farming, sewage and wastewater effluent discharge, should be implemented in all the catchments.

A.1 Appendix 5.1: Inter-Basin Water Transfers in Southern Africa

There are several inter-basin water transfers that have been implemented in Southern Africa for water supply augmentation, irrigation and electricity generation (Slabbert 2007).

Countries	Inter-basin water transfers schemes
Namibia	Kunene—Cuvelai,
	Eastern National Water Carrier (Okavango—Swakop)
South Africa–Swaziland	Komati Scheme,
South Africa	Usuthu Scheme Maputo,
	Usuthu-Vaal Scheme,
	Grootdraai Emergency Augmentation (Orange—Limpopo basin),
	Vaal—Crocodile,
	Tugela—Vaal Scheme,
	Mooi—Umgeni Scheme,
	Umzimkulu—Umkomaas—Illovo Scheme, (Umzimkulu—Umkomaas basin),
	Amatole Scheme (Kei—Buffalo and Nahoon basin),
	Palmiet River Scheme,
	Riviersonderend—Berg River Project,
	Orange River Project (Orange—Great Fish basin),
	Orange—Riet,
	Caledon—Modder,
	Orange—Vaal,
	North—South Carrier
	Vaal—Gamagara Scheme,
	Springbok Water Scheme,
	Vioolsdrift—Noordoewer,
	Turgwe—Chiredzi (Zambezi basin),
South Africa–Lesotho	Lesotho Highlands Water Project (LHWP),
South Africa–Botswana	Molatedi Dam—Gaborone,

Inter-basin Water Transfers in Namibia:

The Eastern National Water Carrier (ENWC) in Namibia is one of the largest inter-basin water transfers in Southern Africa (Slabbert 2007). The ENWC was designed to transport water by canal and pipeline from the Kavango River on the north-eastern border of Namibia, pass Grootfonetin to the storage dams (Omatako, Von Bach and Swakoppoort Dams) north of Windhoek. The undertaking was a four-phase project.

Phase I was completed in 1978 which involved the Von Bach Dam on the Swakop River, the Swakoppoort Dam 55 km below Von Bach, and a pump system to Windhoek, 53 km away. Phase II comprising the earth fill Omatako Dam on the Omatako River, and a pump scheme, which transfers water from the Omatako River to the Von Bach Dam, was completed in 1983. Construction of phase III commenced in 1981 and comprised the 263 km long Grootfontein-Omatako Canal and the Karstland Borehole System. Phase IV, which has not yet been implemented, will link the Kavango River to the Grootfontein/Omatoko Canal (Slabbert 2007).

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Chapter 6
Conclusions and Recommendations

J. P. Msangi

Abstract There is enough water to meet world's demand but uneven distribution has led to unequal access so that some countries and even individuals have more than others. Therefore there is need to share the available water through inter-basin cooperation and investing in joint projects by riparian partners while enforcing water quality management to curb man-induced scarcity. Success calls for strategies and policies that promote and support water quality management. Other undertakings including rainwater harvesting and building storages that regulate water availability over time support these strategies. However caution must be exercised to ensure that smaller storage facilities close to the farming land and settlements are considered alongside the large storages usually constructed for hydro-power generation. Additional strategies include economical irrigation methods such as drip irrigation that should be given priority over cheaper wasteful ones such as flood and sprinkler irrigation and reducing water loss through evaporation by storing water in underground aquifers. A holistic approach in the usage of both surface and ground water resources including inclusive smart partnerships and win–win situations should be encouraged and supported by governments, non-governmental organizations and donors alike.

Keywords Holistic approach · Water harvesting interventions · Transfer of clean technologies · Recharging underground aquifers · Omdel dam and recharge scheme

> Sustainability in Southern Africa, as elsewhere, begins with water availability (Mbuende 1996).

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Conclusions

While there is enough water to meet world's demand, the global average is a largely irrelevant number just like the world's wealth due to unequal access and uneven distribution, some countries and even individuals having more than others. Pollution and miss-management of the available water sources as well as inappropriate technology worsens the situation. UN Secretary General Ban Ki-moon, expressed some sentiments in mid 2012 saying that "there is still enough water for all of us but only so long as we keep it clean and use it more wisely and share it fairly". Wise sharing of the available water calls for inter-basin cooperation and joint projects among riparian partners and neighbors.

Climate change, climate variability and uneven water resource distribution calls for policies that promote and support water harvesting and sharing of the resource across ecological regions as well as across political boundaries. It has been documented by various research scientists and politicians alike that there is high probability that climate change will lead to reduced water availability and greatly reduced food production worldwide particularly in sub-Saharan countries (those in Southern Africa included) as rainfall declines and temperature rises. Adaptation strategies that include effective strategies for water quality management to ensure sustainable livelihoods of millions of people throughout the world particularly those in developing countries have been recommended.

Water scarcity is a recognized norm in a large part of Southern Africa region. The region has very arid conditions in the south-centre and south west of the continent, and is subjected to high climatic variability and highly unreliable rainfall regime which worsens the region's vulnerability to water scarcity particularly where the available water is prone to pollution. The region has unevenly distributed water resources (both temporal and spatial). This unevenness extends to both surface and groundwater resources. Numerous efforts have been made and agreements entered into that aim to share the available water and promote sustainability in different regions all over the world.

Among these regional initiatives undertaken are those entered into between the Southern Africa Member States forming what is popularly known as Southern Africa Development Community (SADC). This regional initiative was formed with the primary objective of integration and cooperation among Member States with water considered as a critical factor to the integrated and cooperative socio-economic development of the region. As such, the coordinated, sustainable and integrated development and management of the region's water resources is expected to contribute to the region's goal of attaining an integrated regional economy built on the basis of balance, equity and mutual benefit for all Member States.

Water management particularly supports the SADC objectives of poverty reduction, food security, energy security and industrial development, as well as being an instrument to promote peace and cooperation amongst the partners. These objectives are summed up by an observation made at the World Summit on

Sustainable Development, 2002 by the former South Africa's President, Nelson Mandela who stated that "water is central to social, political and economic affairs of the continent and the world at large".

The critical importance of water to regional integration and economic development was recognized and appreciated by all SADC Member States and the SADC Secretariat was established and charged with the responsibility of coming up with interventions and management mechanisms and in taking a lead in steering the process. Despite the significant progress made so far, there are several strategic challenges that require further work.

The first challenge emanates from the paucity of binding legal instruments that govern the sharing of the available water resources in the region. The water scarcity rampant in large parts of the region and competing developmental requirements by various sectors within each state may result in disputes and tension over water. Up to date no notable disputes have surfaced but the likelihood cannot be ruled out.

Yet another challenge emanates from the fact that there is widespread poverty in the region, with many people not having access to adequate water for basic human needs especially for domestic and household purposes and in some instances for productive use. The low levels of access to safe drinking water and adequate sanitation adversely impact the livelihoods, health and productivity of the poorest and most vulnerable members of society. The water infrastructure is unevenly developed across the region so that there is unequal allocation of water among sectors with some sectors like the urban areas being better off than rural areas. Inequality is also found within certain sectors such as urban areas where upmarket areas are better catered for than informal settlements.

Further challenges that make it difficult to provide people with water in the region include the key problems arising from uncoordinated planning of human settlements. Substantial numbers of the inhabitants live in rural areas in the south and southwest of the region characterized by very little or no rain at all for long periods; ephemeral rivers are the norm in these parts. Efforts to relocate the people to areas better endowed with water are often met with resistance and stigma due to a general attachment to ancestral land as well as unwillingness to abandon places with graves and significant cultural sites; a tendency common among many SADC communities. A good case in point involves the Topnaar community perched along the Kuiseb River in the middle of the Namib Desert, and facing acute water scarcity, yet they resist relocation (Msangi 2008).

More challenges arise from inadequate and inconsistent water resources information management among the individual states so that there are associated problems for cooperation and planning in shared watercourses. Similarly there is wide range of legal, policy and regulatory frameworks within the member states making it difficult to establish linkages during enforcement at both national and regional levels, posing challenges for consistent implementation of regional initiatives.

Weak linkages between different sectors and weak information flow and inadequate institutional capacity arising from low levels of awareness, education and training hamper comprehensive and integrated development. Limited or lack of appreciation of the finite nature and economic value of water by some sections of the population coupled with limited awareness and/or lack of effective stakeholder participation and involvement in decision making at local, national and regional levels remain a great challenge when addressing water scarcity issues in the region.

There is no universally accepted standard formula to estimate the value of water in the region, particularly amongst Watercourse States. This makes it difficult for such Watercourse States to engage in negotiations on sharing the resource, since consensus on the value of the resources is difficult to achieve. Lack of appreciation of the economic value of water and largely communal ownership of the resource in rural areas have an adverse impact on the effort and commitment to better allocate and manage the resource for optimal benefits both as an economic and social good.

Striking a balance between economic, social and environmental water resources allocation remains a challenge, due to the perception that efficiency is attained if priority is given to commercial economic uses. Closely related to this challenge are the inherent large inefficiencies of water conveyance and use in all countries in the region. Thus a challenge to water management sector is to define and put in place measures that will improve water use efficiency across the region.

There is an overall shortage of human as well as financial resources to fully meet the standards laid out in the regional and national water policies and laws which is a constraint in the effective practical implementation and enforcement of protocol and policy laid down by the regional body. While the relevant laws and regulatory mechanisms are in place, responsible institutions are not adequately manned (SADC 2007). This is a long-term challenge which has been recognized and included in the regional Water Policy document.

Among the adopted principles guiding the development and management of water resources in the region includes a holistic approach in the usage of both surface and ground water resources; the reuse of water; proper pollution management and the provision of environmental requirements. Each member state was tasked with the responsibility of implementing these principles. Evidence pointing to the fact that some of the Member States have embarked on implementation of these principles is obvious from the examples quoted in the text; examples from some Member States including Namibia, South Africa, Zimbabwe and Zambia.

Namibia, in her quest to meet this responsibility, has forged ahead with various undertakings to ensure management of the scarce resource. These include pollution control and water quality management. Over and above instituting water law and regulations pertaining to water management and pollution control and raising awareness of the general public, Namibia encourages relevant research to ensure the attainment of the requirements of both the SADC Protocol and her national legal instruments governing water scarcity management. The three research studies included in this book have shed light on how Namibia is addressing some relevant water pollution issues that could reduce the availability of potable water.

The study carried out in North-central Namibia categorically demonstrates that there is indeed evidence of pollutants entering the water source (canal) and that the pollution is attributable to human activities and polluted surface runoff. The study also shows that the pollution in the water source increased chemical requirements for coagulation and disinfection and also affected the operation of the water treatment plants. Furthermore the study predicts that the pollution of the canal water is likely to increase with more developments in the basin and the corresponding population growth. This will affect the water treatment process significantly resulting in increased water treatment costs and potentially increases in tariffs.

Similarly, the study which monitored the effect of human activities on water quality in the water source for areas in central Namibia confirmed that there was pollution emanating from human activities both in the catchment area and around the water source (dam). The study on the effects on water transfer from two storage dams into a supply dam with the purpose of alleviating water scarcity in central Namibia found out that there are significant effects resulting from the water transferred from the storage dams into the supply dam. The influence of water transfers on water quality of the supply water body caused complications during water treatment due to high ammonia, high dissolved organic carbon and high turbidity arising from water transferred from the other two dams.

Building water storage infrastructure contributes greatly towards water resources management and in addressing water scarcity. Increasing storage capacity to ensure regulated water availability over time is one viable strategy in addressing water scarcity and promoting sustainability. In many countries such infrastructure provides water for domestic and industrial development; for irrigated agriculture and for reducing the variability of water flows to producers and minimizing risks associated with inadequate or unreliable rainfall regime. Large water infrastructures also offer important source of renewable energy.

Recommendations

For all Member States in SADC, the future lies in facing the water scarcity and management collectively as a block as well as smaller individual groups comprised of riparian states or as individual countries because individual groups/countries are faced with very different challenges when it comes to water management. For example, similar to Namibia which has resorted to water recycling and water reuse to meet escalating demands, South Africa advocates among other interventions, water recycling by food industries (Appendix) an intervention not popular with other Member States.

The potential for cross boundary tensions and conflict should be accorded deserving attention. While all Member States in SADC have institutional mechanisms for allocating water and resolving conflict within national boundaries, cross-border institutional mechanisms require strengthening. Win–win situations should be encouraged and supported by governments, non-governmental organizations and donors alike.

Similarly, inclusive smart partnerships should not only include formal governmental agreements but should include civil society participation at all relevant levels. This will provide opportunities to involve the water users themselves in managing the quality of limited water supplies and would create room for inclusion of indigenous knowledge in the management of scarce water resources as well as land management which directly affects water as a resource. One of the main issues in these partnerships should be management of water quality to uphold water potability.

Many indigenous technologies and practises which have existed for generations should be studied and promoted even if it is in combination with scientifically tested inputs. The civil society, the users and managers at the grass root levels, are as essential to sustainable water scarcity management as are scientists with "advanced" skills. Water harvesting experience shows how community-led initiatives can be scaled up through partnerships.

The study carried out in North-central Namibia recommends that pollution prevention measures should be taken as a matter of urgency to reduce the amount of pollutants getting into the canal which will consequently reduce the amount of chemicals required for water purification and thus curb scarcity of potable water. To uphold the SADC Water Protocol and its Principles, measures such as the enforcement of buffer zones for development along the canal, community education and improvement of sanitation in the settlements along the canal is recommended to be enforced to prevent further pollution to the canal.

The study on water transfers to meet water demands in central Namibia recommends that there should be continuous monitoring of the effects of water transfers and that filtration structures such as gabions should be installed at the inlet of the receiving water body to filter debris, humic substances, suspended solids and other organic matter before the water flows into the dam. This will minimize the concentration of dissolved organic carbon and ammonia which are released during the decomposition of debris and organic matter. To ensure sustained good water quality at the supply dam and lower treatment costs, the water quality of the three dams should be managed in an integrated manner to include catchment management measures (controlled cultivation, cattle and game farming, sewage and wastewater disposal).

Further, the study recommends that more intensive testing be carried out to attain higher precision in detecting pollution sources. In this regard NAMWATER, the managing agent charged with providing potable drinking water to the country's population, should carefully address the dangers of waste water disposal particularly that which contain chemicals found in cosmetics. Over time these chemicals could accumulate to be a major threat to the balance of the aquatic ecosystem. These imbalances may affect the water quality in the long run so as to increase water purification costs. Additionally, the study recommends that more effective disposal of solid waste from around the water source as well as periodic cleaning of the dam to remove debris should be instituted. Filtration structures should also be installed to minimize the quantity of debris entering the water body from the catchment area.

Large infrastructure programs should be subjected to thorough impact studies for their negative impacts on the environment and to the vulnerable people in particular. However, the benefits of large infrastructures are many and should not be over shadowed by the negative impacts. While the contribution of large-scale infrastructure to irrigation and power generation should not be understated, neither should the potential contribution of small-scale infrastructure. Small-scale water harvesting has the potential to store water efficiently, thereby reducing risks as well as to store water close to where it is needed. For example the large volume of water stored in Mozambique's Cahora Bassa or Zambia's Kariba Dam (largely supporting hydro-power generation) does not help small farmers in drought prone parts of the countries. At the time of constructing the huge dams smaller storage facilities close to the farming land and settlements should have been considered alongside the large storages (Hathaway 2008).

The appropriate mix of water (Basilwizi-Trust 2009; Hathaway 2008; Ng'ambi 2006) infrastructure is best decided at national and local levels through dialogue between governments and people. Thus, the real choice is not usually between big and small. Economical irrigation methods such as drip irrigation should be given priority over cheaper wasteful ones such as flood irrigation and sprinkler irrigation (Fig. 6.1).

Reducing water loss through evaporation by storing water in underground aquifers is another intervention that should be encouraged throughout the region. This method has proved very beneficial to many areas such as the dry coastal area in Namibia where dam-construction combined with groundwater recharge is used to manage water scarcity by cutting down water loss through evaporation. Namibia's coastal area, synonymous with the Namib Desert, is characterised by high temperatures and staggering high evaporation rates. Here, the Omdel dam and

Fig. 6.1 Well managed drip irrigation for a tree crop

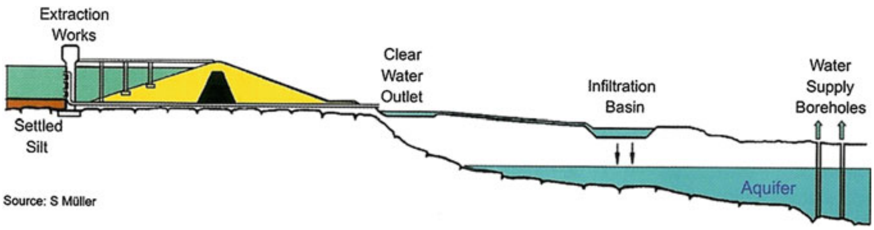

Fig. 6.2 Omdel dam and recharge scheme

recharge scheme built to increase sustainable yield of the aquifer supplying water to the central coastal towns is designed to store flood waters of the ephemeral river (Omaruru). The stored water is released to infiltration basins downstream of the dam wall after the silt has settled thus allowing recharge of groundwater aquifer protected from direct evaporation. The stored water is then recovered through boreholes and fed into water distribution system as needed (Muller n.d.; NAMWATER 2012) (Fig. 6.2).

Rain water harvesting is yet another intervention that should be encouraged as a measure towards managing water scarcity in the region. Rainwater, normally available for short periods followed by prolonged dry seasons can be captured and managed wisely to preserve its potability. Where piped water is non-existent or is a luxury only the rich can afford, rain water harvesting offers a reliable source of clean drinking water. If appropriately stored, such water can also support home gardens; small irrigation projects and watering domestic animals which provide nutritional products that enhance people's health.

Rain water harvesting done from roof catchments, rock catchments and constructed protected ground catchments is stored in appropriate storage tanks, surface or sub-surface dams until when needed. Protected ground catchments are ideal for both individual homesteads and small institutions. Constructed ground catchments are more hygienic than those which collect water from bare ground. The protected catchments get cleaned regularly before the onset of the rains and old water in the tank is flushed out before new supply is received.

Appendix

South Africa will run dry by 2050, should no action be taken to conserve water. It is pertinent that the key players in South Africa's food industry implement strict water saving measures through the use of water recycling, to help address the impending water deficit that is threatening food security and produce all around the country.

According to Gareth, Managing Director of Ecowize—a leading hygiene and sanitation company servicing the food sector, it is crucial for food producers and manufacturers to introduce elements of strict control through implementations of water saving disciplines, as water will always be a basic necessity.

"All industries need water and therefore more people need to make the effort to recycle water and come up with other innovative ways to save and protect natural water resources," (Lloyd-Jones 2012).

According to Lloyd-Jones, there is a critical need for food producers and manufacturers to realize the magnitude of this crisis and to take responsibility and make concerted efforts to recycle water and prevent water wastage often caused by-pipe bursts, water leaks and unscheduled use of water.

"Cost-effective water-saving disciplines include having a water recycling system in place whereby used water is drained through a filtration process to rid all solids and then put through a chemical intervention to make it suitable and fit to use back into plant facilities. This water can then be used to wash areas down such as drive ways."

Lloyd-Jones says companies should introduce universal benchmarks to set the right amount of water required for particular jobs, without any wastage. "This can be achieved via three important variables—value, the pressure and the temperature of the water."

"These variables need to be balanced and measured on a periodic basis as this determines the problem. One way of doing this is by measuring where water pressures are fluctuating as this will expose inconsistencies or leaks by conducting thorough root cause analysis, farmers will be able to determine the cause of the problem and eliminate chances of it re-occurring". Furthermore, he says in order to avoid unscheduled use of water, food producers and manufacturers need to introduce strict elements of control that set aside specific times that apparatuses such as hoses can be used. They can also use specially designed couplings that are manufactured to protect the hose against leaks.

Lloyd-Jones says food producers and manufacturers will also be able to save enormous amounts of water by providing staff with efficient water saving training that help to develop their skills and knowledge in order to enable them to identify the cause of water waste and ways to solve such problems.

"For best results and in order to ensure that staff make a concerted effort, farmers can implement water saving incentives such as performance pay systems, which are driven by how well staff obey set water saving disciplines," says Lloyd-Jones.

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