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Anja du Plessis

Freshwater Challenges of South Africa and its Upper Vaal River

Current State and Outlook

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ISSN 2364-6934 ISSN 2364-8198 (electronic)
Springer Water
ISBN 978-3-319-49501-9 ISBN 978-3-319-49502-6 (eBook)
DOI 10.1007/978-3-319-49502-6

Library of Congress Control Number: 2016962704

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Acknowledgements

The author would like to acknowledge and thank the University of Johannesburg where the PhD thesis was completed as some sections of the thesis has been used in the completion of this book. The author would also like to thank Rand Water and the Department of Water and Sanitation for water quality data upon which the conclusions of this book are based upon.

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Chapter 1
Global Water Availability, Distribution and Use

Water is one of the most widely distributed substances across the world's surface and is crucial for a variety of aspects of human health, development and well-being as well as for the functioning of natural ecosystems. It has been recognised as a fundamental human right internationally and consequently needs to be managed both effectively and efficiently to ensure that global water needs are met. The distribution of water across the globe is uneven and the availability thereof becoming an increasingly major concern. The main water use sectors, grouped in terms of agriculture, industrial (includes industrial activities, mining and energy) as well as municipal/domestic, recreational and environmental water use, have an influence on water availability through physical water abstraction as well as through water degradation. Global challenges in terms of water availability and water use are highlighted. Focus is placed on the availability, distribution and use of freshwater resources on a global scale.

1.1 Introduction

Water is one of the most widely distributed substances to be found in the natural environment and constitutes the earth's oceans, seas, lakes, rivers and underground water sources. This substance is crucial for various aspects of human health, development and well-being. The United Nations has recognised the importance of this resource by incorporating it into the Millennium Development Goals (MDGs) and by proclaiming the years 2005–2015 as the International Decade for Action 'Water for Life' (UN Water 2011). The importance of water has continued to be recognised with the incorporation thereof into the new Sustainable Development Goals (SDGs) which are Global Goals primarily set to transform the world and part of the 2030 Agenda for sustainable development. Water has thus been

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*, Springer Water, DOI 10.1007/978-3-319-49502-6_1

continually recognised as a fundamental human right internationally and it is vital that it be managed effectively and efficiently on a global and national scale. This - Chapter will focus upon the availability, distribution and use of freshwater resources on a global scale.

1.2 Water Availability and Distribution

Approximately 75% of the Earth's surface is covered by water. However, this is just an estimate as the dynamic nature and permanent motion of water makes it difficult to reliably assess the total water stock/store of the earth. Current estimates are that the earth's hydrosphere contains approximately 1386 million km^3 of water. However, not all of these resources are potentially available to humans since freshwater is required by the agricultural sector, industries, and domestic and recreational users (Kibona et al. 2009; Cassardo and Jones 2011; Lui et al. 2011).

Figure 1.1 shows that 97% of the Earth's water occurs in oceans and is saline. Approximately three percent (3%) of the water on Earth is fresh water and its physical state varies from being a liquid, to becoming a gas or a solid. Approximately 69% of the Earth's fresh water is locked up in glaciers, ice caps and permanent snow cover in the polar regions. Groundwater accounts for 30% of the freshwater on Earth, while only 0.3% of all freshwater is contained in river systems, lakes and reservoirs (Kibona et al. 2009; Cassardo and Jones 2011; Lui et al. 2011).

As indicated in Fig. 1.2, approximately 99% of water is described as unfit or unavailable for human consumption. The remaining one percent (1%) consists mainly of groundwater, which can be difficult and costly to obtain. Only 0.0067% of the total water on Earth is fresh surface water that can be used. This leaves a total of around 2120 km^3 of freshwater that is available for human use and consumption (Cassardo and Jones 2011).

Numerous desalinisation plants, in fact more than 14,000, have been developed over the globe as a result of limited freshwater supplies. These plants produce over 60.5 billion litres of water daily and most of the Persian Gulf countries rely on such plants. Thus, without the implementation of these desalinisation plants or reverse osmosis technologies, the world's potable water supply would be very limited (Kibona et al. 2009; Curry 2010).

The most fundamental function of water is firstly as a prerequisite for life on Earth and secondly, as a commodity or economic resource. These two roles are constantly in conflict with each other in many areas of water usage. This has led to the exploitation of water through human activities which has in turn placed huge risks on aquatic ecosystems and the life that they support (Pimentel et al. 2010).

The distribution of water across the world's surface also plays a role. It is important to note that both the human population and water resources are unevenly distributed across the Earth's surface. Areas that are densely populated by human populations do not necessarily coincide with regions that are rich in water supplies. The minimum basic water requirement for human health is 50 L per capita per day and the minimum amount of water required per capita for food is approximately

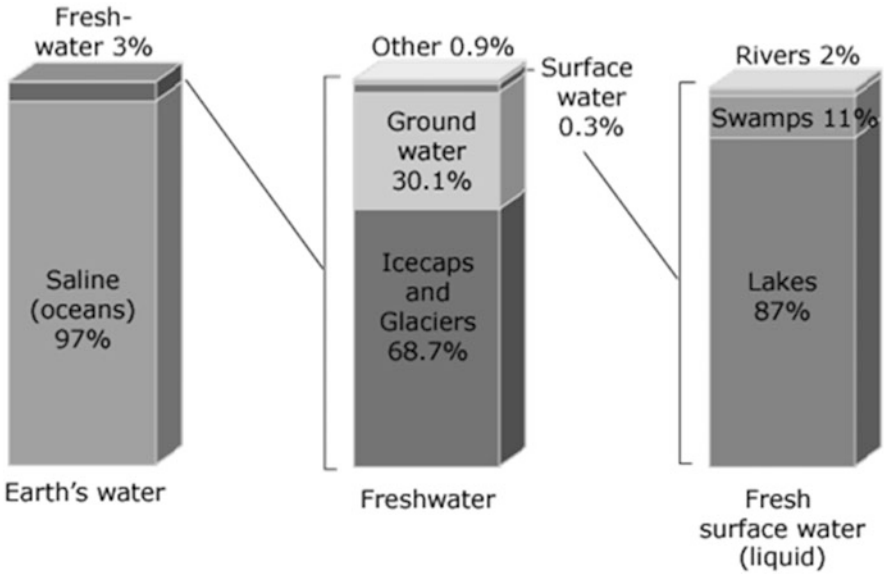

Fig. 1.1 Distribution of the Earth's water (Lui et al. 2011)

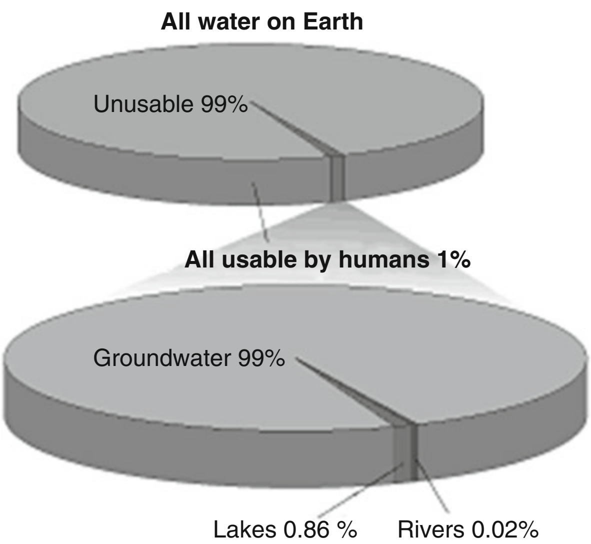

Fig. 1.2 Water available on Earth for human consumption (Lui et al. 2011)

400,000 L per year, as estimated by the World Business Council for Sustainable Development. However, regions such as the United States of America (USA) consume more than eight times that amount for human consumption and four times that amount per year for food production. This confirms the fact that water resources are unevenly distributed across the world (Kibona et al. 2009; Pimentel et al. 2010; Cassardo and Jones 2011). According to these minimum requirements, the total amount of water available on Earth is sufficient to provide for the whole population. However, most of the total freshwater is concentrated in specific regions, such as North America, while other regions such as the Middle East and North Africa face a water deficit (Cassardo and Jones 2011).

The changes that are currently being experienced in the further development of regions across the world have resulted in a pandemic array of changes in the terrestrial component of the water cycle. These changes relate in part to universal transformations in the global water system and are not isolated. Amongst others, they include the universal changes in freshwater systems in terms of the following.

Physical characteristics: These include long-term changes in surface and subsurface moisture storage and runoff, and persistent changes in precipitation and hydrological patterns. It is said that researchers generally have a limited understanding of the global scale manifestation of local hydrological mechanisms, as well as the intensity of such changes in the different regions. The altercation of physical characteristics of freshwater systems through developments such as mining operations can change characteristics such as the system's soils, wetland hydrology and geomorphology within one region and have unintended altering effects or cumulative impacts such as increased sedimentation or the altercation of a different freshwater system in another connected region or area (Alcamo et al. 2008).

Chemistry and biology: These include long-term alterations in the flow of nutrients and sediments toward the oceans, as well as the key levels of water quality and habitat parameters. The over utilization of freshwater systems through various human activities can be accompanied with an influx of nutrients within aquatic habitats and consequently greatly reduce aquatic organisms and hold severe consequences for aquatic ecosystems. An example of this could include the continued increase of waste water in the degradation of water quality on aquatic ecosystems and freshwater fisheries which remain an important protein for the poor population (Alcamo et al. 2008).

Anthropogenic water use and withdrawal: These include rapidly changing patterns of water consumption across different economic sectors and regions. Industrialised countries now tend to be associated with reduced withdrawals of water while the volumes of water withdrawn in the developing regions are increasing. These trends have caused changes in water stress patterns with uncertain global implications (Alcamo et al. 2008).

1.3 Water Use

Fresh surface water is mainly used across the globe as it can be easily extracted. It has recently been estimated that the approximately 69% of worldwide usage of water is for agriculture, mainly in the form of irrigation; 22% for industrial purposes, eight percent (8%) for domestic purposes, and one percent (1%) for recreational use (Kibona et al. 2009; Rosegrant et al. 2009; Cassardo and Jones 2011).

Many water usage sectors are facing increased competition between themselves in respect of water rights and withdrawals. For the business risk to be mitigated for industries and to ensure that the needs of future generations can be met, trade-offs need to be made and water management strategies and technologies should be developed or improved upon within the global, national and regional contexts. Business as Usual is no longer an option, but the capacity to develop Business Unusual models that are financially viable, socially acceptable and ecologically sustainable, remains a persistent constraint due to different visions, priorities and perspectives of water within the different sectors, regions and populations of the world.

1.3.1 Agriculture

In terms of water usage, agricultural activities dominate over all the other sectors on Earth. The agricultural sector's usage of water resources includes the water used for irrigation, for livestock, for fisheries and for aquaculture. The water removed for agricultural purposes is used solely for irrigation. The percentage of agricultural water used for irrigation is relatively higher in low- and middle-income countries. An alarming fact is that between 15 and 35% of the water that is withdrawn for irrigation purposes in low and middle-income countries is used in an unsustainable manner. To highlight this point is the fact that the amount of cultivated land in these countries increased by 24% since 1964, whereas the size of irrigated areas more than doubled between 1970 and 1995 (Kibona et al. 2009; Rosegrant et al. 2009; Lui et al. 2011; UN 2012).

As indicated in Fig. 1.3, approximately 70% of the world's irrigated land occurs in Asia, which accounts for approximately 35% of the area of cultivated land. The highest proportion of irrigated cultivated land occurs in the Democratic Peoples' Republic of Korea, which has a total of approximately 73%. Japan follows with 65%, China with 55%, while the proportions for irrigated land in other countries range from 20 to 40%. The agricultural water usage proportion for South Africa ranges from 47 to 63% and as such also follows the trend of agricultural water usage being the dominant sector (Kibona et al. 2009; Rosegrant et al. 2009; Lui et al. 2011; UN 2012).

The projections for global population growth are approximately two to three billion people over the next 40 years. Food demand will increase by 70% by 2050. With the increase in the demand for food and the fixed water supply, food products will need to be produced using less water. This can only be achieved by improving irrigation methods and technologies. There is the potential to increase the areas of cropland over the globe. However, approximately five to seven million hectares (0.6%) of this farmland is lost annually as a result of accelerating land degradation and urbanisation. This has caused the amount of cultivated land per person to decline even further from 0.4 ha in 1961 to only 0.2 ha in 2005 (Kibona et al. 2009; Rosegrant et al. 2009; Lui et al. 2011; UN 2012).

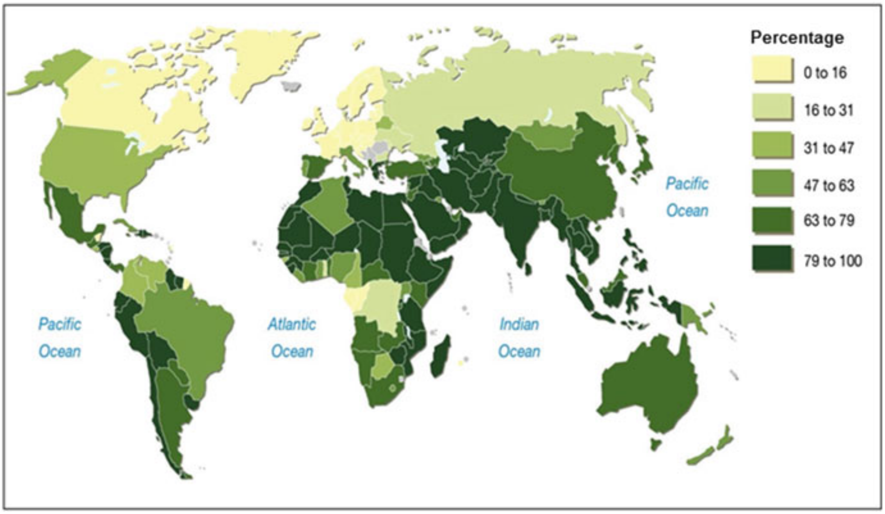

Fig. 1.3 Agricultural water usage across the world (FAO 2008)

In order to increase agricultural outputs, one needs to increase both the water and energy consumption of the world—which would in turn lead to intensified competition between the different water-usage sectors and place more pressure on the world's water resources. The main challenge that is facing the agricultural sector is not so much to grow 70% more food in 40 years, but rather to make 70% more food available to the world's growing population.

1.3.2 Industries, Mining and Energy

Industrial water usage is the second-largest consumer of water in the world. The consumers include economic entities such as mines, oil refineries, manufacturing plants, as well as energy installations using water for the cooling of power plants. The demand for water by the industrial sector of a country is generally proportional to the average income level of its people. Industrial water withdrawals constitute five percent (5%) in low-income countries as opposed to the above 40% in some high income countries (Refer to Fig. 1.4). A number of countries in Asia are now developing their economies around industrial development so that water usage in this sector will increase over subsequent years (Kibona et al. 2009; Lui et al. 2011).

The industry that uses the most water is the energy sector. Energy and water are intricately connected. All sources of energy and electricity require water in the production process, while energy is also required to make water available for human consumption through pumping, transportation, treatment, desalinisation and irrigation.

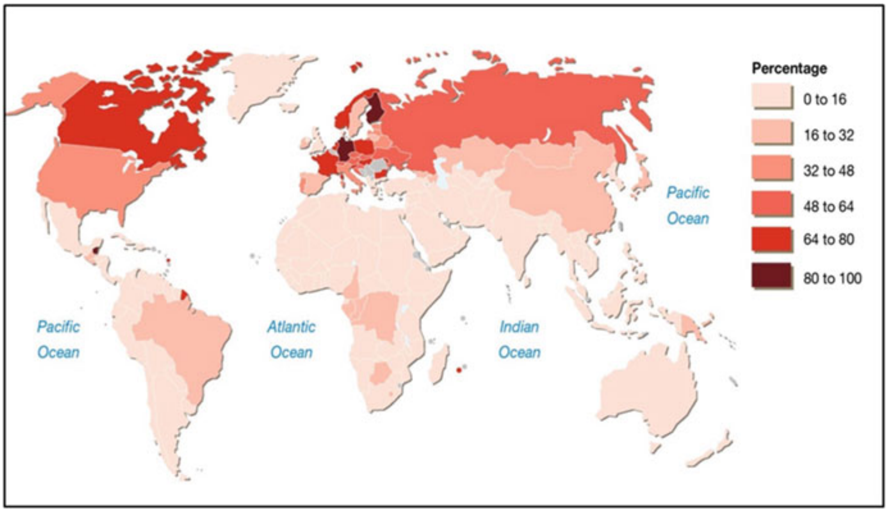

Fig. 1.4 Industrial water usage across the world (FAO 2008)

The EIA (2010) has predicted that global energy consumption will increase by approximately 49% from 2007 to 2035. This increase in energy consumption will place pressure on the energy sectors of the world and in turn also on water resources (UN 2012). In terms of South Africa, the energy situation is following the same trend. More coal-powered stations are being developed by Eskom in order to meet the needs of the growing population and the economic sector. This holds significant environmental impacts for the future if the precautionary principles are not taken into account.

1.3.3 Domestic, Recreational and Environmental

Domestic activities account for eight percent (8%) of the world's water consumption and constitute the third-largest water consumer across the globe. This category includes drinking water, bathing, cooking, sanitation and gardening activities. The estimated basic household water requirements are at around 50 L per person per day but excluding water for gardens (Gleick 2006; Kibona et al. 2009). Approximately 2 L of the 50 are used for drinking, 20 L for sanitation, 15 L for bathing, and 10 L for cooking. This estimate is however exceeded by most countries.

Recreational water use accounts for only one percent (1%) of the world's water consumption but this proportion is increasing slowly. This type of water use is associated with reservoirs. The water is categorised as recreational if the reservoir is kept fuller for storage purposes than it would otherwise be. Recreational activities include boating, angling, water skiing, as well as swimming, to name a few. The aforementioned types of water use are usually non-consumptive. However, sportsfields, such as golf courses, can be considered as consumptive.

Recreational water usage can have further consequences for other water usage sectors such as agriculture as it can reduce the availability of water for users at specific times. A good example of this is in the event of water being retained in a reservoir to allow for boating in late winter. The storage of water in the specific reservoir may cause this water to be unavailable to farmers during the spring planting season (Kibona et al. 2009; Lui et al. 2011). Even though recreational water use accounts for very little water withdrawal, it does compete with other water users such as the agricultural sector. As in the case of industries, recreational activities will have to compete for water in the future as a result of the increase in the world's population.

Lastly, environmental water usage uses the least water of all the categories mentioned previously and benefits ecosystems rather than human beings. The percentage of environmental water usage is very small. Notwithstanding this, the total water usage is increasing as a result of artificial wetlands and lakes that are intended for creating habitats for various wildlife species. As in the case of recreational water usage, environmental water usage is non-consumptive but may reduce the total volume of water that can be made available to other users at specific times and locations. With an increase in the adoption of ecocentric and biocentric value systems, we can expect more water to be directed in the future to ecosystems and nature reserves than to human needs (Kibona et al. 2009; Lui et al. 2011; UN 2012).

Widespread physical evidence suggests that human activities have already reached or even exceeded the renewable water limits in numerous regions across the globe. The chronic over-extraction of groundwater, which is now a common practice in many important food-producing regions and in large urban areas, is the clearest indicator of unsustainable water usage. Much of China's North Plain, the USA's Great Plains and California's Central Valley, parts of the Middle East and North Africa, the valley of Mexico and parts of South-east Asia are exceeding their groundwater recharge levels (Kibona et al. 2009).

The lower reach of China's Yellow River has run dry every year this decade with an entire section extending for 600 km from the river mouth upwards. China's Yellow River is just one example, as many other rivers across the world are currently running dry during all or part of the dry season when irrigation farming is at its most prolific—pointing to excessive water usage (Kibona et al. 2009).

Many water usage sectors are facing increased competition in respect of water withdrawals. In order to mitigate the business risk for industries and to ensure that the needs of future generations can be met, trade-offs need to be made and water management strategies and technologies should be developed or improved upon within the global, national and regional contexts. These sectors therefore have an influence on water availability through physical water abstraction as well as through water degradation. We therefore need to look at water quality as well before we determine the degree of water scarcity or water stress within a region or area.

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Chapter 2
Global Water Quality Challenges

Water is the cornerstone for good health and well-being of humans and ecosystems as well as in terms of socio-economic development. Water quality is becoming a global concern due to the significant role that it plays in economic and social development. Water quantity has received far more attention from investors, scientists and the public than water quality however, the quality of water is just as important for satisfying both basic human and environmental needs. Poor water quality can be linked to quantity as water that has been polluted cannot be used for agriculture, industry or domestic water usage and effectively reduces the amount of water available in a given region. The world is faced with numerous water quality concerns such as eutrophication, salinization, sedimentation, microbial pollution as well as toxic pollution problems. Poor water quality is accompanied with economic costs in the form of health-related costs, the degradation of ecosystem functions, high water treatment costs, reduced property values, as well as impacts on economic activities such as agriculture and manufacturing. Focus is placed on the types of pollution as well as the main global water contamination problems or challenges.

2.1 Introduction

An adequate water supply and an appropriate water quality level are key elements in the good health and well-being of humans and ecosystems, and in social and economic development. Water quality is becoming a global concern as a result of the significant role that it plays in economic and social development. The degradation of water translates directly into social and economic impacts and the deterioration of the environment. Even though there have been successes on the local scale in the improvement of water quality, there is no evidence to suggest that an overall improvement on a global scale has been achieved (UN 2012).

Water quantity and water quality are linked as both are key determinants of supply. Water quantity has received far more attention from investors, scientists

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Springer Water, DOI 10.1007/978-3-319-49502-6_2

and the public than water quality. However, the quality of water is just as important for satisfying both basic human and environmental needs. Poor water quality is linked to quantity as water that has been polluted cannot be used for agriculture, industry or domestic water usage and effectively reduces the amount of water available in that given region (Palaniappa et al. 2010; UN 2012).

Water quality has been defined by numerous authors over a long period of time. Meybeck and Helmer (1996) state that it is difficult to provide a simple definition of water quality since the complexity of the factors determining water quality and the large variety of water quality parameters used to describe the status of the water bodies in quantitative terms need to be taken into account and viewed as a whole. The interpretation of the concept, water quality, has changed over the past century, having come to incorporate a broader definition of water-usage requirements and also improvements in the ability to measure and interpret water properties (Meybeck and Helmer 1996; Manahan 2000; Davis and McCuen 2005).

Meybeck and Helmer (1996) define water quality in the context of the aquatic environment as the composition and condition of the aquatic biota, as determined by a set of concentration levels and specifications and by physically differentiating between inorganic and organic substances. Such a definition permits a description of the current temporal and spatial variations caused by factors that are inherent/intrinsic and extraneous to the water body.

The quality of water is considered to be relative as it depends not only on the function of its condition and what it contains, but also on its usefulness and usability, the latter being affected in turn by whether the quality is considered to be ‘good’ or ‘bad’ (UN 2012). Davis and McCuen (2005) define water quality in terms of significant physical and chemical parameters that determine the usability of water for a specific purpose. As a result, water quality guidelines are developed and regulated by legislation, and present a range of criteria which the water must meet in order to deal with the maximum threshold level of the pollutant or the minimum input of important substances such as purification chemicals. These guidelines allow the quality of the water in a water body to be managed according to the end use of the water (Lester and Birkett 1999; Davis and McCuen 2005).

The interaction between the physical and ecological processes within the water body has numerous effects and consequences in terms of water quality. These interactions can either promote aquatic health or be associated with negative impacts that degrade the overall quality of the water in the water body (Schladow and Hamilton 1997). ‘Pure’ water only exists in laboratories as all substances in the environment can be considered as pollutants—depending on their concentration. This is the primary reason why health professionals prefer the term ‘safe’ water to ‘clean’ water (UN 2012).

The quality of surface water, as well as groundwater, is influenced by both natural processes and human activities. Water naturally contains dissolved substances, non-dissolved particulate matter, as well as living organisms, to help maintain vital biogeochemical cycles. There are, however, exceptions where these naturally occurring substances trigger water quality problems, which can be detrimental to human health (UN Water 2011). Saltwater intrusions can also affect the quality of water by increasing the salinity levels in coastal inlets as in the case of Cyprus and the Gaza Strip (UN 2012). In Bangladesh, approximately 90% of the population use groundwater as a primary freshwater source and have been at risk in recent decades of arsenic exposure (van Halem et al. 2009).

Furthermore, the connection between water quality and quantity can take different forms in terms of groundwater and surface water. Excessive pumping of groundwater over time without enabling the aquifer to replenish itself can diminish water quality in various ways. The increased concentrations of naturally occurring compounds can become dangerously high as the volume of water decreases. A good example of this is in India where fluorosis could potentially threaten the health of millions of people as long as excessive withdrawals of groundwater by pumping persist (Stellar 2010; UN 2012).

The United Nations Environment Programme (UNEP) identified seven water quality issues that were globally significant for trend monitoring by the Global Environmental Monitoring System's (GEMS) Water Programme. These seven significant global, continental and sub-continental water quality issues include the following:

- Organic wastes derived from municipal sewage discharges, as well as agro-industrial effluents;
- Decaying aquatic plants and organisms owing to low oxygen levels in water bodies caused by the eutrophication of surface waters by point and non-point inputs of nutrients and organic matter;
- Irrigated areas threatened by salinisation and polluted return waters;
- Fertilisers and pesticides applied for agro-chemical purposes and leading to the contamination of surface water;
- Industrial effluents, which contain a variety of organic and inorganic matter;
- Mining effluents and leachates from mine tailings which affect surface waters on a large scale; and
- The acidification of fresh surface water resulting from the long-range atmospheric transportation of pollutants (UNEP GEMS WATER 2005).

Water quality is thus primarily altered through human activities on land that in their turn generate water pollutants or affect the availability of water. These seven water quality issues coincide with the pressures on water, as well as the water quality issues that prevail in South Africa and in the Upper Vaal Water Management Area (WMA).

2.2 Main Types of Water Pollution

Water pollution is deemed to be one of the world's major environmental problems and is associated with various environmental, social and economic issues. A discussion of water pollution follows, with brief reference being made to the major types of pollution sources.

There are numerous definitions of pollution. Cairns and Lanza (1972) define pollution as the appearance of some environmental attribute about which the affected community has inadequate information and for which it is incapable of giving an appropriate response. Davies and Day (1998) define water pollution as water which is offensive to human, animal or plant life. Pollution is defined by Lester and Birkett (1999) as the introduction of substances or energy by humans into the environment that causes hazards to human health, harm to living resources and ecological systems, damage to structures or amenities, or interferes with the legitimate use of the environment. Pollution can also be defined as the introduction of substances or energy directly or indirectly by humans into the environment which results in deleterious effects which are harmful to living creatures and natural phenomena, hazardous to human health or that hinder certain activities (Lui et al. 2011). Thus, water pollution can be described as that which has anthropogenic impacts on the quality of the water in the water body. Such water does not meet the required quality standards for its intended use and is, as a result, described as being polluted.

Increasing population numbers and the advent of industrialisation have caused the range of requirements for water to have increased in concert with the greater demand for improved water quality. Each water-usage activity, including water abstraction and the discharge of wastes, leads to specific and rather predictable impacts on the water quality of the water body (Meybeck and Helmer 1996; USEPA 2006; Lui et al. 2011). Anthropogenic sources, which have various negative impacts on water quality, could be either point or diffuse/non-point pollutants (Ellis et al. 1989; Lester and Birkett 1999).

Organic matter derived from various human activities is considered to be a major source of water pollution. The decomposition and breakdown of the organic matter by micro-organisms requires oxygen. As a result, severe organic pollution may lead to a rapid decrease in the oxygen content of the water body and a reduction in the number of aquatic organisms, such as fish and invertebrates (Apsite and Klavins 1998; Voutsa et al. 2001).

However, Meybeck and Helmer (1996) state that no clear distinction can be made between the two types of sources since a diffuse source on a regional or local scale may result from a large number of individual point sources. The main difference between the two is that a point source can be identified, treated or controlled. On the other hand, diffuse sources, consisting of a number of point sources, can also be managed, provided that all point sources have been identified.

The main point sources which contribute to the pollution of freshwater have their origins in the collection and discharge of domestic waste water, industrial and mining waste, and also certain agricultural activities such as animal husbandry. Other agricultural activities, such as pesticide spraying or the application of fertilisers, are considered to be diffuse sources of pollution. Furthermore, the atmospheric ‘fall-out’ of pollutants is also considered to be an example of a diffuse source polluting freshwater resources (Meybeck and Helmer 1996; Voutsa et al. 2001; Strahler and Strahler 2005).

2.2.1 Point Sources

A point source pollutant is defined by Meybeck and Helmer (1996) as an input of pollution that can be attributed to a single outlet. Lester and Birkett (1999) define a point source as a defined point of entry of the pollutant into a watercourse. Thus, a point source of pollutants can be identified and controlled relatively easily since the pollutant enters the water body at a specific point and can be managed through the issuing of licences and permits.

Point sources are localised. As a result, one can use the spatial profiles of the water quality of the affected water body to locate such sources. Untreated or inadequately treated sewage disposal systems are the major point sources of pollution for the world’s freshwater bodies. Other point sources could include mines and industries. A domestic sewer with a constant discharge of pollutants over time is considered to be a good example of a point source. Fluctuating or occasional discharges are attributed to leaks and accidental spillages (Meybeck and Helmer 1996; Helmer and Hespanhol 1997; Lester and Birkett 1999; Ashman and Puri 2005; Bosman and Kidd 2009).

Thus, the main point sources of pollution are where sewage and industrial effluents enter a water body and could have various negative effects on the overall

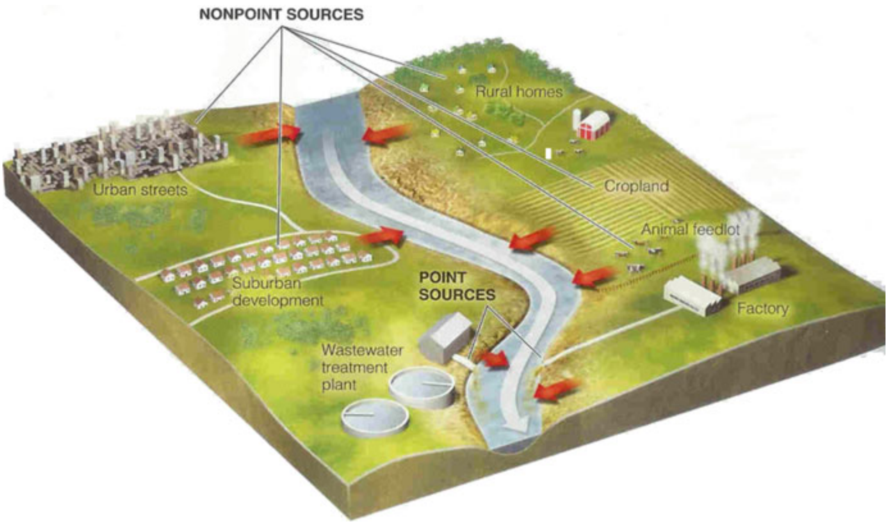

Fig. 2.1 Main point and non-point source pollutants (Miller 2005)

quality of water in the water body. Figure 2.1 shows the main point and non-point source pollutants.

2.2.2 Non-point Sources

Non-point or diffuse pollutants have become increasingly important in the last few decades as they are associated with numerous environmental problems such as eutrophication, acidification and emission dispersion (Rode and Suhr 2007; Bosman and Kidd 2009). Meybeck and Helmer (1996) describe non-point or diffuse sources as pollutants that are not ascribed to a single point or human activity.

However, as previously stated, these sources might be due to numerous individual point sources feeding from a large area into a water body. Thus, it is more difficult to identify diffuse sources since pollution could have its origins in numerous sources and cannot, therefore, be controlled through the issuing of licences. The main variables that play a role in the scale and nature of diffuse pollution are the soil type, rainfall, and the occurrence of storms (Lester and Birkett 1999; Poor et al. 2006).

Nakano et al. (2008) state that agriculture can be considered to be a major contributor in terms of non-point source pollution. A high concentration of dissolved nutrients such as phosphates, nitrates and sulphates occurs in regions where human activities are practised on a large scale and in close proximity to a water body. It is clearly evident that water bodies that are located in regions where there is a high level of agricultural activity are especially enriched with nutrients. Such conditions occur as a result of the acids that are generated through the decomposition of fertilisers which in turn cause selective leaching or the dissolution of soil and rock (Nakano et al. 2008).

According to Meybeck and Helmer (1996), the main diffuse sources, also described as non-atmospheric diffuse sources, that have a negative impact on the quality of the water are as follows:

- *Agricultural runoff*: Erosion from surface and subsoil drainage systems transfers organic and inorganic soil particles, nutrients, pesticides and fertilisers to adjacent water bodies;
- *Urban runoff*: Runoff which is not channelled into a main drain or sewer may contain contaminants derived from the combustion of fossil fuels, bacteria, metals and industrial organic pollutants. Fertilisers and pesticides emanating from urban gardens and landscapes may also be transported by urban runoff to an adjacent water body.
- *Waste disposal sites*: Facilities including municipal and industrial solid waste disposal units, liquid waste disposal units and dredged sediment disposal sites also contribute to groundwater pollution. These sources can be regarded as either point or diffuse sources, depending on the relative size of the disposal facility, as well as the receiving water body.

- *Other sources*: Diffuse sources could include pollution from boating activities and also pollution from the exploitation of open lakes or dam resources (Meybeck and Helmer 1996; Christensen et al. 1997).

Poor et al. (2006) state that water pollution is closely linked to the runoff from impervious surfaces, especially in the case of urban areas. Diffuse sources could be considered permanent or continuous, periodic or seasonal, occasional or accidental. The associated effects vary according to the receiving water body, as well as the particular use to which this water is put (Meybeck and Helmer 1996).

According to the United Kingdom Environmental Protection Agency, the main sources of diffuse pollution are the following:

- Nutrients (e.g. phosphorus and nitrogen) arising from the overuse of fertilisers and manure;
- Pathogens and soil from livestock stables, paddocks, pastures and grazing areas;
- Pesticides as a result of poor storage and the inefficient handling of them, runoff;
- Poorly stored organic wastes from slurries, surplus crops, sewage and sludge;
- Urban areas, as well as construction and demolition sites;
- Faecal pollution caused by overloaded and badly connected sewage facilities;
- Oils and hydrocarbons from vehicle maintenance operations;
- Solvents derived from industrial areas; and
- Metals and chemicals from atmospheric deposition, abandoned mines and industrial processes (CIWEN 2003).

Lester and Birkett (1999) describe the main pollutants arising from diffuse sources as acid rain and mine water. Negative environmental conditions such as inadequate hydrological controls, as in the case of human interference in the movement of water, also give rise to unfavourable hydrological conditions. Figure 2.2 presents the main pollutants and the associated pollutant pathways.

Industries and factories spread out over an area also act as diffuse sources of pollution in that the industrial, activities and operations carried out at the various sites in the area release effluents, which contribute to the high pollution levels in their discharged water. Surface water sewers facilitate the process of draining the area in question of its polluted water as they drain into the water body in the area oils, hydrocarbons, sediment, phosphorus and other acidifying pollutants and solvents are deposited in the water body (CIWEN 2003).

Since the rapid growth in the population has placed pressure on the agricultural sector to increase productivity, fertilisers and pesticides are being increasingly used. Cultivated lands and pastures are also diffuse sources of pollutants in that they contribute pollutants to a water body when surface runoff, leaching and spray drift carry the organic and non-organic waste that they generate and release. The type of cultivation and the local drainage pattern are factors that play a role in the dissemination of diffuse pollutants arising from agricultural activities (Dabrowski et al. 2001; CIWEN 2003; Oberholster and Ashton 2008).

The various types of diffuse pollutants present themselves in the form of nutrient leaching in the case of surface water bodies and groundwater. Water bodies are

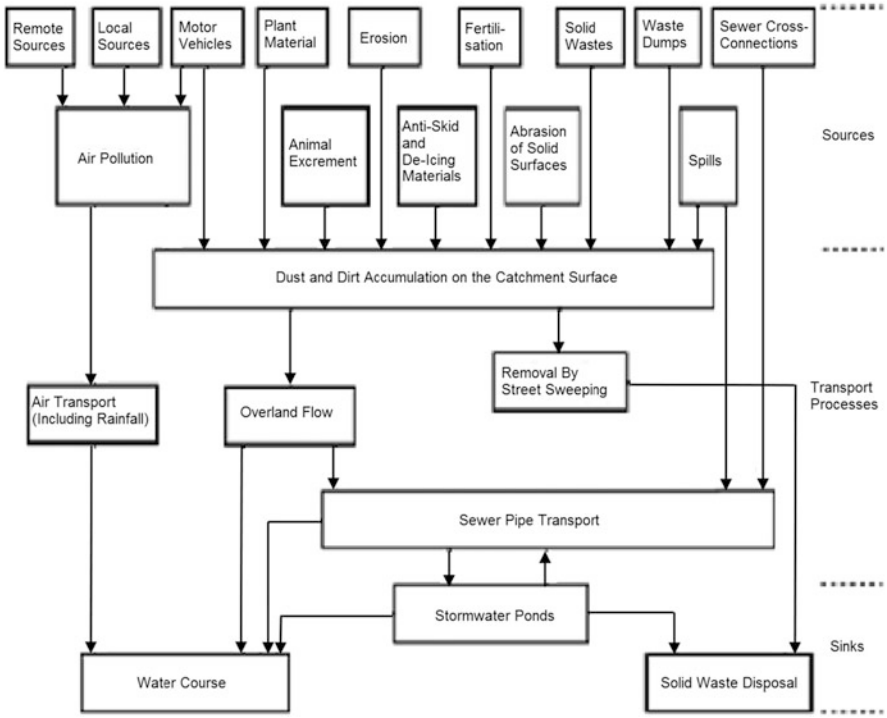

Fig. 2.2 The main sources of pollutants and the pollutant pathways (adapted from Chae and Hamidi 1997)

enriched with nutrients such as phosphates, as well as nitrates, which cause eutrophication and a change in the local ecology. Such conditions could have numerous impacts on human and animal health (CIWEN 2003; Oberholster and Ashton 2008).

Van Rensburg et al. (2008) conclude that the irrigation of the soil during dry periods could be associated with salt accumulation in a region that has a semi-arid or an arid climate. This could cause the salts to leach out into the soils and could subsequently contaminate the water body. However, such processes depend on the type of soil, as well as on the irrigation practices. Thus, agricultural activities could significantly contribute in numerous ways to degradation in the quality of the water.

Recreational activities contribute to diffuse pollution by releasing diffuse pollutants such as pesticides, suspended solids, nutrients and faecal pathogens into the water body (DWS 1996). Other sources of water pollution could include chemical reactions on exposed geological formations, air emissions from burning substances, as well as the disposal of materials into the water body (Thompson 2006). Accidental water pollution could arise from many possible sources such as burst pipes and tanks, leaks, oil spills and fires (Rand Water 2005).

Thus, numerous anthropogenic activities could cause a decline in the quality of the water in a water body, irrespective of the route that the effluent takes. The degradation of water quality, on account of all of the contaminants could result in a change in the species composition and an overall decline in the aquatic health of the affected water body. Environmental problems have been present since the rise of civilisations. However, these problems have increased in magnitude. Much damage may be unforeseen or unintentional. The concept of environmental stewardship is thus necessary to ensure sustainability and the maintenance of healthy ecosystems (Durell et al. 2001; Lui et al. 2011).

2.3 Main Contaminants and Problems

The Blacksmith Institute and Green Cross Switzerland developed the first list of the world's most polluted places in 2006 and 2007 which included the "Dirty Thirty" index detailing the sources and effects of pollution at each identified cases. The report identified the world's top ten worst pollution problems which pose the greatest risk to human health and the environment (Blacksmith Institute 2008). These pollution problems include the following unranked pollution issues:

- Artisanal Gold Mining
- Contaminated Surface Water
- Groundwater Contamination
- Indoor Air Pollution
- Metals Smelting and Processing
- Industrial Mining Activities
- Radioactive Waste and Uranium Mining
- Untreated Sewage
- Urban Air Quality and
- Used Lead Acid Battery Recycling

The rest of the toxic twenty include abandoned mines, Agrotoxins and Persistent Organic Pollutants (POPs), Arsenic, Cadmium, Chromium, Coal Power Plants, Garbage dumps, Industrial Estates, Polychlorinated biphenyls (PCBs), old and abandoned chemical weapons and lastly oil refineries and petrochemical plants which all affect surrounding waterbodies at different degrees and extents.

The seven worst pollution problems within the African continent was also identified by the report and include abandoned mines, artisanal gold mining, contaminated surface water, indoor air pollution, oil refineries and petrochemical plants, radioactive waste and uranium mining and untreated sewage. These pollution problems are in many ways the end result of poverty, high levels of urbanisation, lack of infrastructure and formal sector employment and overstretched governments which contribute to dangerous conditions for human health.

As previously discussed, the quality of water is affected by the products of human activities and natural processes that are channelled in various ways. These activities and processes change the physical, chemical and biological attributes of a water body and affect the quality of the water through sedimentation, raised or reduced temperatures, altered pH levels, the addition of nutrients, heavy metals and non-metallic toxins, persistent inputs of organic waste and pesticides, as well as some biological factors. These contaminants could combine to cause worse or different impacts than the cumulative effects of a single pollutant (UN 2003; Kundzewicz and Krysanova 2010; Palaniappa et al. 2010; UN Water 2011). The main water contaminants or problems will be discussed briefly with relevant examples.

2.3.1 Nutrients

Nutrient enrichment increases the rate of primary productivity to excessive levels and is most often associated with the addition of nitrates and phosphates from agricultural runoff but also from human and industrial waste. This has become the most widespread problem associated with the quality of water. The nutrient enrichment of a water body leads to the overgrowth of vascular plants such as hyacinths and algal blooms and also to the depletion of dissolved oxygen in the water column. These impacts on the water body are associated with stress or the death of aquatic organisms (Carpenter et al. 1998; Carr and Neary 2008; UNEP GEMS WATER 2009).

Cyanobacteria produce toxins that could affect humans and animals that ingest or are exposed to these affected waters. Nutrient enrichment can also be associated with the acidification of freshwater ecosystems and in turn impact upon the biodiversity of that region. The long-term impacts of nutrient enrichment are the depletion of oxygen and the elimination of species that have higher oxygen requirements. Nutrient enrichment therefore affects the structure and biodiversity of the entire ecosystem (Carpenter et al. 1998; Carr and Neary 2008; UNEP GEMS WATER 2009). Some water bodies over the world have become hyper-eutrophic owing to an excess of nutrients and have been declared ‘dead zones’ as all the macro-organisms have been eliminated.

The highly eutrophicated Lake Udaisagar located within Udaipur in India is a world famous example of nutrient enrichment. Located close to the city of the Lake and Fountains i.e. Udaipur (popularly known as “Kashmir of Rajasthan”), the lake receives pollution such as city sewage, industrial wastes from industrial areas such as industries of Mewar industrial area as well as agricultural runoff through the Ahar River. Heavy algal blooms have been observed which have posed threats to the water supply of some industrial factories such as the Hindustan Zinc Ltd. Factory (Vijayvergia 2008).

High concentrations of nitrates, phosphate, chloride, high total alkalinity, high organic matter contents, total dissolved solids as well as increased temperature have consequently led to the overall deterioration of the lake through the enhancement of the eutrophication process as shown in Fig. 2.3. Nutrient enrichment of the lake has

Fig. 2.3 Eutrophication of Lake Udaisagar, located in Udaipur, India (Panoramoi 2015)

been accompanied with correlated phenomena such as the flowering of water, increased fish mortality, foul odour, blue-green colouration of the water and an overall decrease in recreational value.

Eutrophication and toxin-producing cyanobacteria (blue-green algae) blooms pose significant threats to South Africa's already limited and critical surface water bodies as well and will be discussed further within this context in Chap. 6.

2.3.2 *Erosion and Sedimentation*

Erosion can be defined as a natural process which provides sediments and organic matter to water systems. Human activities have altered the natural erosion rates, however, and raised the rate of sedimentation in water bodies all over the world. As a result, the physical and chemical processes within these water systems have been affected, as well as the adaptations to pre-existing sediment regimes. Sedimentation causes a decline in primary productivity, reduces and impairs spawning habitats, and harms fish, plants and river-bed-dwelling invertebrates. The water chemistry of the water system is altered as fine sediments attract nutrients and toxic contaminants (Carr and Neary 2008; UNEP GEMS WATER 2009).

Both rivers and dams are therefore affected by erosion and sedimentation. Sedimentation is still the most serious technical problem faced by the dam construction industry even after many decades of research. It has been estimated that 50 cubic kilometres of sediment (nearly one percent of global reservoir storage capacity), is trapped behind dam walls every year which in turn consume almost one-fifth of the world's storage capacity. Sediment filled rivers also cause abrasion of turbines and other dam components which in turn affect the generating efficiency of these components by eroding and cracking the tips of turbine blades which are expensive to repair (McCully 1996).

The deterioration of the Yangtze River in China is a good example of how the combination of sedimentation and unprecedented pollution led to the once pristine river becoming unfit for drinking. The river basin has been plagued by increasing pollution from rapid, large-scale industrial and domestic developments as well as agricultural runoff for the past five decades. The annual discharge of sewage and industrial waste in the river has reached 25 billion tonnes which accounts for 42% of the country's total sewage discharge and 45% of total industrial discharge. Agriculture contributes 92% of nitrogen discharge into the river and shipping discharges further exacerbates the river's declining health (WWF 2016). In December 2009, some members of the Greenpeace organisation discovered that a factory was directly draining sewage into the river and in September 2012, the Yangtze River turned a bright red colour near Chongqing which is believed to be due to industrial pollution i.e. dye as shown in Fig. 2.4.

The Yangtze River is experiencing dramatic eutrophication but also sedimentation. The river is the fourth largest sediment carrier in the world due to the proportion of arable land, damming and erosion from land conversion occurring in the basin. In addition the Three Gorges Dam has exacerbated water pollution within the basin even more by the impounding of waters, trapping sediment and increasing eutrophication. The increased sediment yield in combination of the Three Gorges Dam, 660 km downstream, has led to the reduction of velocity of the river, increases its water depth and has altered the natural flow regime.

Sedimentation of water bodies can therefore lead to the alteration of water chemistry within a water body as these fine sediments attract nutrients and toxic contaminants which is accompanied by exacerbated pollution and eutrophication problems.

2.3.3 Water Temperature

The temperature of a water body plays an important role in biological functions such as the signalling for spawning and migration of species, and also influences metabolic rates in aquatic organisms. A change in the natural water temperature could impair reproductive success and growth patterns and also lead to long-term declines in the fish population and in other aquatic organisms. An increase in water temperature causes the water column to hold less oxygen and thus impairs the metabolic function and reduces fitness (Peters and Meybeck 2000; Carr and Neary 2008; UNEP GEMS WATER 2009).

Thermal pollution of water bodies can be caused by both natural and anthropogenic sources. Natural sources can include volcanic and geothermal activity under the oceans and seas which trigger lava to warm surrounding water. Lightening has also been found to introduce an increase in temperature of water especially in oceans. In terms of anthropogenic sources of thermal water pollution these can include nuclear power plants, coal fired plants, industrial effluents, domestic sewage and hydro-electric power. Nuclear power plants which also include the drainage from hospitals, research institutions as well as nuclear experiments and explosions, discharge unutilised heat along with traces of toxic radio nuclides into nearby water

Fig. 2.4 (**a**) Sewage pollution being pumped directly into the river by a factory and (**b**) Yangtze River turned red due to industrial pollution (Brad 2013; Daily Mail 2012)

bodies. Heated effluents from nuclear power plants have been found to be 10 °C higher than the receiving waters as indicated in Fig. 2.5.

In terms of coal fired plants, the condenser coils within these plants are cooled from nearby waterbodies. The discharge of the heated water has been found to increase the affected waterbodies by 15 °C. This heated effluent in turn decreases the dissolved content of water and the sudden fluctuation in temperature, referred to

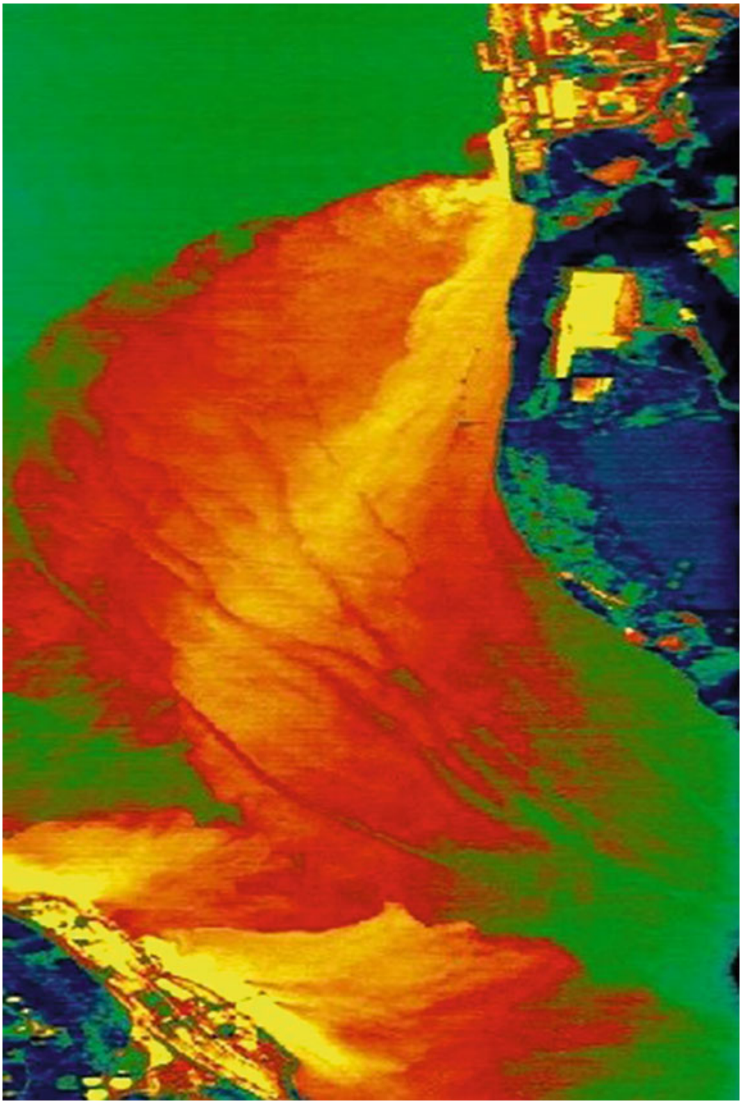

Fig. 2.5 Thermal pollution from a point nuclear power plant in India (Worldpress 2010)

as “thermal shock”, leads to the death of fish and other aquatic organisms. Industrial effluents which may include textile, paper, pulp and sugar manufacturing release large amounts of cooling water along with effluents. The increase in sudden and heavy organic loads consequently causes a severe drop in levels of dissolved oxygen. Domestic sewage discharged into surrounding waterbodies with minimal or no treatment have higher organic temperature and organic load which can lead to the decrease of dissolved oxygen content and ultimately results in anaerobic conditions which release a foul and offensive gases in the water. This consequently leads to the development of anoxic conditions which result in the death of aquatic organisms.

The generation of hydro-electric power can also lead to negative thermal loading. Other thermal pollution sources include industries and power plants which use water to cool machinery and discharge the heated water into surrounding streams, deforestation and the removal of streamside vegetation causing less shade, soil erosion caused by construction causing waterbodies to be more exposed to sunlight and lastly by poor farming practices. All of the mentioned sources or causes for thermal water pollution may lead to the following detrimental effects within the affected waterbody:

- *Reduction in dissolved oxygen*—dissolved oxygen decreases with an increase in temperature.
- *Increase in toxicity*—an increase in temperature, increases the toxicity of poison already present. A 10 °C increase in temperature doubles the toxicity effect of potassium cyanide which can be accompanied with massive mortality of fish.
- *Interference in biological activity*—Temperature is significant in terms of physiology, metabolism and biochemical processes which control respiratory rates, digestion, excretion as well as the overall development of the aquatic organism as a whole.
- *Interference in reproduction*—Increase in temperature will affect fish activities such as nest building, spawning, hatching, migration as well as reproduction.
- *Direct mortality*—Thermal pollution is directly responsible for mortality of aquatic organisms. An increase in temperature leads to exhaustion of microorganisms which consequently decreases the lifespan of fish. Failure of the respiratory and nervous systems take place above a specific temperature.
- *Food storage of fish*—Thermal shock can alter seasonal variation in the type and abundance of lower organisms which leads to shortages of right food for fish at the right time.

Thermal water pollution therefore leads to an overall loss of biodiversity and is accompanied by large ecological impacts as it can result in mass killings of fish, insects, plants as well as amphibians.

2.3.4 Acidification

The pH of an aquatic ecosystem is the determinant of the health and biological characteristics of that system. Industrial activities such as mining and the generation of power from fossil fuels can result in the localised acidification of an affected freshwater system. Emissions associated with the combustion of fossil fuels and other atmospheric processes could cause the formation of acid rain and affect large regions over the globe. Young organisms are primarily affected as they tend to be less tolerant to low pH values. A decline in the pH level could also be associated with the mobilisation of metals from natural soils and could lead to fatalities amongst all aquatic species (Peters and Meybeck 2000; UNEP GEMS WATER 2009).

The mining of the Iron Mountain in the USA which commenced in 1896 is a good example of the environmental consequences of mining. The environmental effects only became apparent a few years after the opening of the mine in 1902 in the Sacramento River, near Redding, when fish kills were recorded. Several private lawsuits were also served against the Mountain Copper Company for severe air pollution which denuded the vegetation of the surrounding area. Operations however continued and caused acid mine drainage as well as contaminated sediment deposits which were deposited at the bottom of Spring Creek which threatened fish and other aquatic organisms downstream. The water samples taken by the remediation activities which commenced in 1990 showed negative pH values which made the water the most acidic to be sampled and described to be 6300 times more acidic than battery acid (USGS 2013) (Fig. 2.6).

The acid mine drainage from the Iron Mountain was determined to be among the most acidic and metal-laden water anywhere on earth. The acid mine drainage into the Sacramento River have threatened this ecologically sensitive water body that hosts several threatened and endangered species of anadromous fish which includes the steelhead and types of Chinook salmon. Furthermore, approximately 90,000

Fig. 2.6 Acid mine drainage from the mining of the Iron Mountain in the United States of America (Swenty 2016)

residents of the City of Redding is also situated downstream of the site and could potentially threaten the quality of the drinking water supply.

Acidification of water bodies can therefore have detrimental widespread environmental consequences such as the loss of biodiversity as well as the overall degradation of ecological health and possible human health impacts. South Africa as well as some areas within the Upper Vaal WMA are also increasingly affected by the acidification of waterbodies and will be discussed in more detail in Chap. 6.

2.3.5 Salinity

The plants and animals in freshwater systems do not tolerate high salinity levels very well. Anthropogenic processes such as agricultural runoff, groundwater discharge from oil and gas drilling fields or other pumping operations, may cause the build-up of salts in the water body. The type of salt that is introduced by these activities is not necessarily the same as that which occurs naturally. The ratio of potassium build-up could be higher than that for sodium salts which would result in raised stress levels to the aquatic organisms by affecting their metabolic functions and their oxygen saturation levels. Riparian and emergent vegetation would also be affected. Furthermore, high salinity levels affect the characteristics of natural wetlands and marshes; they could reduce the extent of the habitats of certain aquatic species and reduce agricultural activity and crop yields (Peters and Meybeck 2000; Carr and Neary 2008; UNEP GEMS WATER 2009).

Australia's landscape is naturally saline with agricultural lands containing vast amounts of salt, held deep within the soil profile where it doesn't affect plant growth. The salt within the continent's soil does however become a problem when too much water is applied. It is estimated that 2.5 million hectares of land have become salinized due to the introduction of European farming methods. Much of the affected land was valuable farmland especially the West Australian wheatbelt and the crop and pasture zones of the Murray-Darling Basin with once highly productive irrigated lands. The increased salinity within these regions is posing a significant threat to the country's water resources as it contaminates surface water and groundwater supplies. The potential impacts for the rising salinity includes the contamination of hundreds of thousands of people's drinking water supply, significant cost and a threat to the economy of Adelaide and other South Australian towns. The rise in salinity also threatens native plant and animal species which are already threatened by extinction (Australian Academy of Science 2006).

Bangladesh has also been experiencing an increase of salinity which is now threatening the country's coastal communities. The rising salt in the soil and water has led to the discontinuation of cultivation within the southwest district of Satkhira. Low lying communities are being increasingly threatened by the effects of climate change and the worsening of drinking and irrigation water scarcity. The rising temperatures, change in rainfall patterns as well as the reduction of stream flow have been accompanied by an increase in river salinity which has led to the damaging of the fishing industry as well as shortages of drinking water and a lack of irrigation water during the dry-season (Rahaman 2013).

Salinisation of water resources therefore do not only pose a significant risk for a country or region's economy and agricultural sector but also for its native fauna and flora which could be driven to extinction as well as the affected region's drinking water supplies.

2.3.6 Pathogenic Organisms

Pathogenic organisms include bacteria, protozoa, as well as viruses, and rank amongst the most serious and widespread water quality contaminants in the world—especially in regions where the access to safe and clean drinking water is limited. The organisms are one of the leading global human health hazards and the greatest risk of microbial contamination comes from consuming water that has been contaminated with pathogens from human and/or animal faeces (Carr and Neary 2008; UNEP GEMS WATER 2009).

Human and animal faeces are not the sole causes of pathogenic organisms. Some of the pathogenic micro-organisms are free-living in certain areas and are capable of colonising a new environment as soon as they are introduced. They include bacterial species and a few types of amoeba. The ingestion of these free-living pathogenic micro-organisms is associated with major health problems and poses significant human health risks. Special attention is given later in this chapter to the impact of degraded water quality on human health (Carr and Neary 2008; UNEP GEMS WATER 2009).

The deposition of untreated or minimally treated sewage is among the world's top ten worst pollution types. This type of pollution contains liquid wastes of human faeces as well as wastewater from non-industrial human activities such as bathing, cleaning etc. Sewage is dumped into local waterways in many poor areas of the world due to the absence of no practical alternatives. This poses a major risk to human health as it contains waterborne pathogens that cause serious human illness but also destroys aquatic ecosystems threatening human livelihoods.

According to the United Nations, approximately 2.6 billion people on Earth do not have access to adequate sanitation and sewage facilities. In many cases "open defecation" is still practiced and the bacteria from the excrement are often tracked back into the community, contaminating water supplies and spreading disease. India is ranked as the number one country in the world without sanitation with approximately 818 million of its population not having access to adequate sanitation and sewage facilities. Approximately 80% of the country's sewage in Indian cities flows into the water systems. This has turned some water resources to be too polluted to use and has led to almost the whole country's groundwater to have unacceptable nitrate levels due to sewage leaching into India's groundwater aquifers. The sewage situation has been described to be a "ticking health bomb" as half of the urban Indian population depends on groundwater sources for drinking, cooking and bathing which puts them in direct risk. The lack of focus on sewage systems in the region has led to no single city having a sewage system which covers the entire population and in most cases sewage simply mixes into open drains and storm water drains, polluting water sources as illustrated in Fig. 2.7 (TNN 2013).

However, it is not only poor countries or regions that are faced with sewage pollution problems. Toronto in Canada has been found to have the worst sewage pollution within the Ontario region. The primary cause for sewage pollution is due to antiquated, outdated sewage infrastructure and combined sewers which manage both sewage and storm water. This has consequently led to the seepage of billions of litres of partially treated and raw sewage into Lake Ontario which could cause major effects to the local ecosystem, reduce biodiversity and increase levels of *Escherichia coli* (*E. coli*) which could cause illness. The July floodwater which wreaked havoc in people's homes in 2013, may have been contaminated with some overflow sewage. The region has however stated that investments have been made into the replacement of combined sewers which will limit the effect on drinking water supplies. The sewage seeping into Lake Ontario will however have an effect as one in four people on Ontario rely on the lake for drinking water as all drinking water is treated before it reaches their taps. The increase of sewage pollution within Lake Ontario will however have economic effects as the cost for treating water is steadily increasing (Armstrong 2013).

The pollution of freshwater resources through pathogenic organisms is therefore a widespread serious threat to both human and environmental health and is not only

Fig. 2.7 Untreated sewage from the Shilong Dump in India (Blacksmith Institute 2016)

a prominent problem within developing regions. In terms of South Africa, the pollution of its freshwater resources through pathogenic organisms is increasing due to a multitude of factors and will be focussed upon in Chap. 6.

2.3.7 Trace Metals, Human-Produced Chemicals and Other Toxins

Trace metals include arsenic, selenium, zinc and copper which occur naturally. Human activities such as mining, manufacturing and agriculture, could lead to the mobilisation of these trace metals out of the soils or waste products into freshwater. Trace metals even at very low concentrations might be toxic to certain aquatic organisms and impair reproductive and other functions within the affected organisms. The introduction of trace metals into water systems can result in deformities in animals such as birds and also kill off many of these species, as well as many others which occur in the affected environment (UNEP GEMS WATER 2009; Kundzewicz and Krysanova 2010).

The numerous anthropogenic-generated organic chemicals are also considered to be contaminants of freshwater bodies. These organic chemicals are produced through the application of pesticides, through industrial processes and through the breakdown of products and other chemicals. The broken-down material and dissolved particles enter water bodies through surface water and groundwater (Carr and Neary 2008).

Pollutants such as pesticides and other non-metallic toxins are used all over the globe and are transported over long distances to areas where they have never even been produced (UNEP GEMS WATER 2009). These organic contaminants are also referred to as POPs and commonly contaminate groundwater through percolating down and carrying leachates through the soil. They could also contaminate surface waters through runoff from agricultural and urban landscapes.

Invertebrates might ingest non-lethal doses of these materials and store them in their tissues. As larger organisms consume these contaminated prey species, the concentrations of these organic chemicals and toxins will bio-intensify to toxic levels. Some of these materials and pesticides may break down in the environment itself. However, these broken-down products could also be toxic and could accumulate in sediments. When scouring or any other disturbances occur, large volumes of these products could be released from the sediments into water bodies (UNEP GEMS WATER 2009).

Synthetic and toxic chemicals are anthropogenically released into the environment, affecting water, soil and air. Toxic pollution can impact the surrounding environment as well as the human population living close to the source of pollution in terms of experiencing serious health effects such as birth defects, development disorders, respiratory problems, cancer and in some cases death. The top ten toxic pollution problems of the world include the following in no particular order:

- *Lead-Acid Battery Recycling*—although the industry attempts to reduce the number of disposable batteries and solid waste, batteries contain high number of toxic metals and chemicals which lead to water and soil contamination.
- *Mercury and Lead pollution from mining*—More than two million people around the world are affected by mining and ore processing operations which produce hazardous chemicals found near sites which include lead, chromium, asbestos, arsenic, cadmium and mercury.
- *Coal Mining (Sulphur Dioxide and Mercury Pollution)*—The high levels of mercury in the air is commonly overlooked and is a serious threat to human health in terms of lung cancer, asthma, bronchitis and may affect foetus's brain development.
- *Artisanal Gold Mining (Mercury Pollution)*—The production process of retrieving gold from mined ore in turn releases more mercury than any other sector. Vaporised mercury can cause developmental disorders and affects the central nervous system of people in the surrounding area through contaminated water and soil.
- *Lead Smelting*—Lead smelting sites release toxic chemicals, primarily iron, limestone, pyrite and zinc during the smelting process aimed at removing impurities from lead ores. This process puts 2.5 million people at risk around the world.
- *Pesticides pollution from Agriculture and Storage*—Approximately two million metric tonnes of pesticides are used annually to destroy targeted pests and unfortunately also has effects on human health from skin irritations to causing cancer. Stockpiles of old and outdated pesticides contribute to the problem as these are mostly improperly stored.
- *Arsenic Groundwater*—This pollution problem affects 750,000 people, mostly in South Asia, where contaminated groundwater is still used by people. This in turn can lead to cancer, blood vessel damage, abnormal heart beat and other illnesses.
- *Industrial Wastewater*—Wastewater from factories may not be limited to batteries, smelting toxins, organic particles, pathogens, methane and carbon dioxide. Minimally treated or untreated industrial wastewater dumped into the surrounding environment contaminates waterbodies as well as soil and lead to immense environmental degradation.
- *Chromium pollution (Dye industry)*—Chromium is used in dye, is critical to the human diet and generally speaking does not cause damage to the human body. However, this industry contains numerous health hazards as Cr IV Chromium is highly toxic and dangerous, enough to cause death in humans.
- *Chromium pollution (Tanneries)*—Cr IV Chromium is used to turn animal hides to leather in tanneries which are primarily centered in South-East Asia. These tanneries are minimally controlled and produce 7.7 million litres of waste water and 88 million tonnes of solid waste daily. This in turn can cause respiratory and heart failure as well as cancer in the brain and kidneys (Conserve Energy Future 2016).

The Blacksmith Institute determined the ten worst polluted places in the world which include some of the following. Dzerzinsk, Russia, where chemicals and toxic by-products of from the Cold War-era chemical weapons manufacturing, potentially affects 300,000 people through poisonous effects owed to its arsenic trioxide content, mustard gas as well as other persistent organic chemicals. It is estimated that 300,000 tonnes of chemical waste was improperly disposed of and around 190 separate chemicals released into the groundwater. This has consequently turned the water into white sludge containing dioxins and high levels of phenol which can lead to acute poisoning and death (Blacksmith Institute 2006).

Kabwe located in Zambia have been polluted with lead and cadmium. The Copperbelt which was discovered in 1902 to contain rich deposits of lead were accompanied with mining and smelting operations almost continuously until 1994 without the government addressing the potential danger of lead. Smelting processes were unregulated and released heavy metals in dust particles, which settled on the ground in the surrounding area. With the smelting operations discontinuing, the city has been left poisoned by immense concentrations of lead in the soil and water from the slag heaps (Blacksmith Institute 2006).

Haina in the Dominican Republic has been severely contaminated with lead from a closed down automobile battery recycling smelter, potentially affecting 85,000 people. The contamination is caused by past industrial operations of a nearby Metaloxa battery plant and has resulted in the contamination of soil as well as severe health effects and lead poisoning (Blacksmith Institute 2006).

There are therefore multiple examples across the globe illustrating the immense effects of toxic pollution which in some cases can be unintended. The mass poisonings due to arsenic contaminated water in Bangladesh has been described as the "largest mass poisoning in history" and is an unintended consequence of humanitarian efforts to alleviate disease in Bangladesh. Many deep tube wells were built to produce water for irrigation and drinking in the 1970s trying to reduce deaths from waterborne pathogens. The move away from disease-carrying surface waters to "clean" deepwell supplies lowered deaths from waterborne illnesses however as time went past, consumers of the deepwell water as well as irrigated deepwell crops begun to show mysterious symptoms which were determined to be of arsenic exposure (Lepisto 2010).

It was found that more than 20% of deaths in the study population of 12,000 can be attributed to arsenic poisoning. Half of the country's population have been exposed to the toxic metal which can cause cancer and long term effects on organs and the cardio vascular system. A larger test population and further studies will assist in defining the health effects of exposure to low levels of arsenic (Lepisto 2010).

An example of human-produced chemicals includes POPs which are toxic chemicals which adversely affect human health and the environment which has become a global issue as they can be transported by wind and water around the world. POPs produced in one country can therefore affect populations and environments far from where they were used and released, persist for long periods of time in the environment and can accumulate and pass from one species to the next through the food chain. This has become a global concern which in turn led to the development of the Stockholm Convention where signed countries of this treaty agree to reduce or eliminate the production, use and/or release of 12 key POPs (Lepisto 2010).

Some of the most well known POPs include Dichlorodiphenyltrichloroethane (DDT) and dioxins. DDT was used to protect people from insect-borne diseases such as malaria and typhus and was a valuable public health tool. This has however led to widespread environmental contamination and the accumulation of DDT in humans and wildlife. High levels of DDT in certain birds of prey have found to cause their eggshells to thin to such an extent that they could not produce live offspring. POPs also cause adverse human health effects by affecting reproductive, developmental, behavioural, neurologic, endocrine and immunologic effects.

Trace metals as well as the multiple human-produced chemicals have therefore serious and detrimental effects on both human health as well as the environment and in some cases can be unintended. The pollution of the world's freshwater resources through toxic pollution have increased significantly with continued industrial and economic development. Countries and regions therefore need to be attentive of the possible negative effects which are associated with these developments to ensure that the health of both the human population and the environment is not adversely affected such as the case of the included examples.

2.3.8 Introduced Species and Biological Disruptions

Freshwater systems are being increasingly affected through the displacement of endemic species. Water chemistry and local food webs respectively are also being increasingly altered and affected by invasive species. The introduction of alien aquatic species into ecosystems has in most cases been deliberately done for recreational, economic or other purposes and has been accompanied by the disappearance of endemic fish and other aquatic organisms from the affected ecosystems. Local watersheds could also be degraded. By clinging to the hulls of recreational watercraft or being expelled through the bilge water of commercial boat traffic, alien species could also be transferred and introduced unintentionally into ecosystems (Carr and Neary 2008).

A good example of how alien species can affect ecosystems lies in the introduction of certain mussel species in the USA into water bodies. They have posed great threats to human infrastructures, clogged up pumps and have led to costly and continual maintenance challenges (de Leon 2008).

Non-native species can therefore create dramatic and unexpected shifts in the dynamics of an ecosystem. The snakehead fish is a good example of how a non-native species can affect an aquatic ecosystem. The fish was nicknamed as the Northern Snakehead "Fishzilla" due to them being characterised by sharp shark-like teeth, a very strong appetite and can lay up to 75,000 eggs a year. The fish can also breathe and migrate on land and search for other waterbodies for up to four days through the use of its primitive breathing organ. These fish were native to Eastern Asian waters and have decimated native food chains in the USA as a result of its introduction (Gonzalez 2011).

Furthermore, in South Africa, alien invasive plant species have altered the quality of the water, reduced the quantity of water, and increased evapotranspiration rates in the affected watersheds. Alien invasive plant species have caused billions of Rands of damage to the country's economy annually and are one of the greatest threats to biodiversity (DWS 1996).

2.3.9 Emerging Contaminants

Owing to the introduction of new chemicals for agricultural, industrial and household purposes, and new testing technologies for detecting contaminants at lower levels, a growing number of contaminants have recently been detected in water bodies. These substances can enter the environment through intentional measured releases, such as in the case of pesticide applications, or as regulated or unregulated industrial and agricultural by-products. Accidental spills or leakages during the manufacturing process or storage of these new chemicals could also have serious consequences (Carr and Neary 2008).

A total of approximately 700 new chemicals are introduced into commerce annually in the USA alone and the application of pesticides worldwide has been estimated at over two million metric tonnes. In spite of their widespread use, the prevalence of these chemicals has remained largely unknown until recently as most testing techniques were unable to detect these contaminants at low concentrations (Carr and Neary 2008; UNEP GEMS WATER 2009).

It can thus be concluded that water is contaminated by a large variety of contaminants, which affect the world's freshwater resources in different ways and have numerous impacts on both the environment and the human population. New contaminants are emerging as technology improves. Therefore, proactive management is needed in order to monitor these contaminants effectively and to ensure that both international and national water quality standards are met.

2.4 Overall Influence on the Environment and Human Health

As indicated in the previous sections of this chapter, freshwater systems are degraded through various activities, from various sources and along various pathways. Ecosystems are among the most degraded systems on the planet as a result of a deterioration in the quality and a decline in the quantity of water (UN WWAP 2009). Freshwater systems have suffered more losses in terms of species and habitats than terrestrial or marine ecosystems have (Revenga et al. 2000). With the degradation of the environment and the irreversible loss of species, the decline in water quality has also resulted in a reduction in the economic value of services provided by these systems which includes their ability to treat and purify water for human consumption and to produce habitats for aquatic species.

The environmental impacts associated with the degradation in the quality of the water are tenfold and have worsened over the past couple of decades as the human population has increased.

2.4.1 Environment

Despite humanity's reliance on flowing freshwater, we have severely affected the quantity of water in our rivers and streams, as well as its quality. Furthermore, we have diminished their ability to render ecosystems able to perform useful functions—which has driven numerous species to extinction. Some 12% of described species live in freshwater and approximately 25% of the world's described vertebrate species depend on freshwater ecosystems at some point in their lifecycle. Sixty percent (60%) of the 227 biggest rivers of the world have been intercepted by dams and other infrastructures which have reduced the volume of sediments and nutrients transported to the downstream stretches (UN WWAP 2003; Vie et al. 2008).

There has been an overall widespread decline in the biological health of inland water bodies. It is estimated that 24% of mammals and 12% of birds relying on these waters are considered to be threatened. More than 50% of native freshwater fish in some regions and nearly a third of the world's amphibians are at risk of extinction (UN WWAP 2003; Vie et al. 2008). The introduction of alien species, especially fish, as well as increased nutrient input rates, poses the greatest threats to native biodiversity (Carr and Neary 2008).

The introduction of alien species has contributed to 54% of extinctions while other water quality impacts contributed 26%. The number of threatened or endangered species varies by region. In Europe, more than 40% of freshwater fish are in imminent danger of extinction, while in South Africa nearly two-thirds of her freshwater species are threatened or endangered (Revenga et al. 2000).

The amphibian populations of the world have also experienced population declines. In fact, nearly half of all described amphibian species have experienced declines in their populations and approximately a third face extinction (Dudgeon et al. 2006). Amphibian species are used as indicator species as they are especially sensitive to water quality disturbances. The overall decline in the amphibian population is thus an indication of the widespread impacts of freshwater pollution globally.

2.4.2 Human Health

Water is stated to be the main agent for disease transmission under specific conditions and needs to be properly controlled in order to minimise the public health risks (Jagals et al. 1997). The overall decline in the quality of the world's water could have significant consequences in terms of food security, the environment and human health (Gleick 1993; Postel 1998). Social and economic development have been limited in various arid regions around the world on account of the water scarcity and the associated decline in the quality of the water—two factors which are often closely associated with poverty, hunger and disease (Gleick 1993; Ashton and Haasbroek 2002).

Water-related diseases are described as amongst the most prevalent causes of illness and death, mainly among the poor in developing countries. The predicted drivers to have the greatest effect on human health via water on a global scale include population growth and urbanisation, agriculture, infrastructure and climate change. There is increasing evidence that climate change can alter global precipitation patterns, which will in turn influence land-based human activities and the associated runoff. Ultimately, degradation in respect of water quality will be the result (UN 2012).

Microbial pollution and metallic contaminants are serious concerns all over the world and the annual death toll arising from water-related diseases exceeds five million people, more than half of which are children. According to the UN, approximately 4400 children under the age of five die every day over the world and it is estimated that five times as many children die each year of diarrhoea than from HIV/AIDS (Simonovic 2002; Fawell and Nieuwenhuijsen 2003; UNEP GEMS WATER 2009; Palaniappa et al. 2010).

Waterborne diseases, which cause gastro-intestinal illnesses (including diarrhoea), are caused by contaminated drinking water, while vector-borne diseases (malaria, schistosomiasis) are passed on by insects and snails which breed in aquatic ecosystems. On the other hand, water-washed diseases (scabies and trachoma) are caused by bacteria or parasites. The majority of those affected by water-related mortality and morbidity are children under the age of five (Briggs 2003; UN 2003). Over the last five decades, the mortality rate from diarrhoea has decreased from 4.2 million deaths per year from 1955 to 1979 to 2.5 million deaths per year from 1992 to 2000. Diarrheal morbidity, however, appears to be on the increase. Furthermore, metallic contaminants such as mercury, arsenic and other metals which are produced by various human activities and some natural processes result in serious health risks such as skin lesions, brain damage, nervous system damage, kidney damage, developmental damage to the foetus, while acute exposure can result in vomiting and even death (Younes and Bartram 2001; WHO 2002; Payment 2003; Palaniappa et al. 2010).

According to the MDG Report of 2012, approximately 780 million people (11% of the world's population) remain without access to improved drinking water. The General Assembly of the United Nations recognised water and sanitation as human rights in July 2010. The Assembly recognised the right of every human being to have sufficient water for personal and domestic use: it must be safe, acceptable, affordable and physically accessible (UN 2012; Elliot 2013). Even though this MDG was achieved 5 years before the scheduled cut-off date, there is still much work to be done and many challenges in the way—as presented in Table 2.1 and discussed in the previous sections of this chapter.

The impacts associated with agricultural, domestic and industrial activities are considered to be the main agents or parameters contributing to the deterioration in the quality of freshwater resources globally (NEPP 1995). Vaux (2001) describes the quality of the world's water as being on the decline. As such, water quality has been recognised globally as a major issue. As a result of its deterioration, disturbances have been noted in ecosystems, which are malfunctioning, and also in the contamination and pollution of surface and groundwater (Ongley 1996; Ashton and Haasbroek 2002).

Both human health and socio-economic development depend on the quality of water. Risks related to human and ecosystem health are closely linked to poor water quality, and they in turn threaten socio-economic development. The costs involved in treating water of a poor quality are high, and projections estimate that with the increasing scarcity of freshwater in the coming years, there will be an increase in attempts to remedy water quality problems and to treat poor quality water. It is thus of great importance that the quality of water should be maintained and that, where

Table 2.1 Reasons for concern regarding the world's water resources (Jackson et al. 2001; WHO 2002; Flint 2004)

Availability of water resources	Quality of water	World security and water
Lake Chad in Africa has shrunk from an area of 25,000 km^2 in 1960 to only 2000 km^2 in 2005	Approximately 4400 children under the age of five die every day across the world and it is estimated that five times as many children die each year of diarrhoea than HIV/AIDS	Four percent of Africa's freshwater species are threatened directly by dams and there are more than 1300 large and medium sized dams of which 40% are in South Africa
One fifth of the world's freshwater fish (2000 of the 10,000 identified) are endangered, vulnerable or extinct	Mass fish kills and disease went from nearly unheard of before 1973 to almost 140 events in 1996	800 million people around the world live under the threat of 'water stress'
The world has lost 50% of its wetlands in the past 50 years	Worldwide infectious diseases such as waterborne diseases are the primary cause of death in children under the age of five	Up to 40% of water is lost owing to water leakages in pipes and canals, one of the main causes being illegal tapping
Two out of every three persons will be living under water-stressed conditions in 2025	More people die from unsafe drinking water per year than from all forms of violence including war	70% of the world's freshwater resources are needed for food production and 50% more freshwater is needed for the growing population

necessary, action should be taken to improve water quality on a regional, national and global scale.

Thus, it can be stated that poor water quality is associated with economic costs in the form of health-related costs, the degradation of ecosystem functions, high water treatment costs, reduced property values, as well as impacts on economic activities such as agriculture and manufacturing. By addressing water quality problems and maintaining satisfactory water quality levels then, numerous lives can be saved and significant financial savings can be made (UN 2012; Elliot 2013).

This begs the question then: 'Is water a global or a local issue?'. On the one hand, a river contaminated by municipal sewage or industrial waste can usually be cleaned up by the local waste water control section of the municipality. To solve the problem of an unreliable local supply of water from a river during particular periods of the year, a reservoir can be built upstream of the region to improve and regulate the supply. However, as a result of the global interconnections, water-users in one river basin or catchment area could be strongly linked to other users beyond the borders of the country in question (Alcamo et al. 2008). Thus water is not only a local issue. Regional and global forces influence the manner in which water is used, as well as the amount used. As such, they also affect the level of water scarcity in a river basin. Furthermore, the future sustainable development of global water resources should concern not only the scientific community, but also governments and the public.

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Chapter 3
Global Water Scarcity and Possible Conflicts

It has been widely recognised that numerous countries across the world are entering an era of severe water shortages. The constant increase in the human population, as well as the increase in water consumption per capita across the globe, has resulted in an increase in water shortages. The limitations in freshwater supply are already present as large areas all over the world are facing the consequences of their dwindling and disappearing water reserves. Water scarcity is a multi-faceted problem which is not just determined by water availability but also water quality and access to safe drinking water. The uncertain influences of climate change also need to be kept in mind as it will also play a role in influencing future water scarcity and stress. It is very likely that the costs of climate change will outweigh the benefits globally due to that precipitation variability is expected to increase, and more frequent floods and droughts are anticipated. Potential conflicts may arise on a local and/or regional level between agriculture, domestic use, industry and the natural reserve. Different types of sub-national conflicts can therefore arise all over the world from water scarcity and be accompanied with immense socio-economic consequences. Focus is placed on global water scarcity, possible influences of climate change, future water availability as well as water conflicts.

3.1 Introduction

It has been widely recognised that numerous countries across the world are entering an era of severe water shortages. The limitations in freshwater supply are already present as large areas all over the world are facing the consequences of their dwindling and disappearing water reserves. In the past, the Middle Eastern and North African countries were the focus of the most attention in terms of water scarcity (Curry 2010).

Extended droughts have plagued many African countries which, in their turn, have generated pleas in the United Nations to the international community for food

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*, Springer Water, DOI 10.1007/978-3-319-49502-6_3

supplies and other forms of relief (Falkenmark 1989). However, parts of China, the USA, and two dozen other countries are also now suffering the effects of water scarcities. Water scarcity and stress is therefore increasing around the world, in both developed and developing countries, and have in some cases been accompanied with developing water conflicts in the form of different socio-economic sectors attempt to keep or expand their water requirements or demands or in the form of the expansion of underlying social conflicts between different classes. Water scarcity is a multi-faceted problem which is not just determined by water availability but also water quality and access to safe drinking water. The uncertain influences of climate change also need to be kept in mind as it will also play a role in influencing future water scarcity and stress.

This chapter will therefore focus on water scarcity on a global scale, access to drinking water, possible influences of climate change on future water availability and water scarcity or stress and lastly look at some examples of water conflicts.

3.2 Water Scarcity

The rapid increase in the human population, as well as the increase in water consumption per capita across the globe, has resulted in an increase in water shortages. Approximately one third of the world's population currently live under water scarcity conditions. The water demands of nearly 80 nations across the globe exceed the available supplies. More than 300 cities across China have inadequate water supplies and in some arid regions such as the Middle East and parts of North Africa, the low annual rainfall and expensive irrigation techniques have culminated in a grim scenario for agriculture in the future. More and more regions are now facing water scarcities (Rosegrant et al. 2009; Kummu et al. 2010; Pimentel et al. 2010).

Figure 3.1 presents a global overview of water availability versus population stress. It also shows the pressure that the population places on the water resources of the Asian continent. This continent supports more than half of the world's population but has only 36% of the earth's water resources.

China accommodates 20% of the world's population but has only 7% of the world's water available to it. Numerous scientists and academics have highlighted the pending predicament for all humankind that will result from high population growth rates and limited natural resources, the latter having been exploited and been depleted since the 1800s. Even though this physical end has not yet been reached, a crisis point from an international security standpoint is already evident in many regions. A large proportion of the world's population will be confronted with severe risks that will be triggered by inevitable droughts in their regions. The water shortages are expected to multiply in the future—even in the absence of the factor of global warming or climate change—as a result of mismanagement and pollution (Shen et al. 2008; Frederiksen 2009).

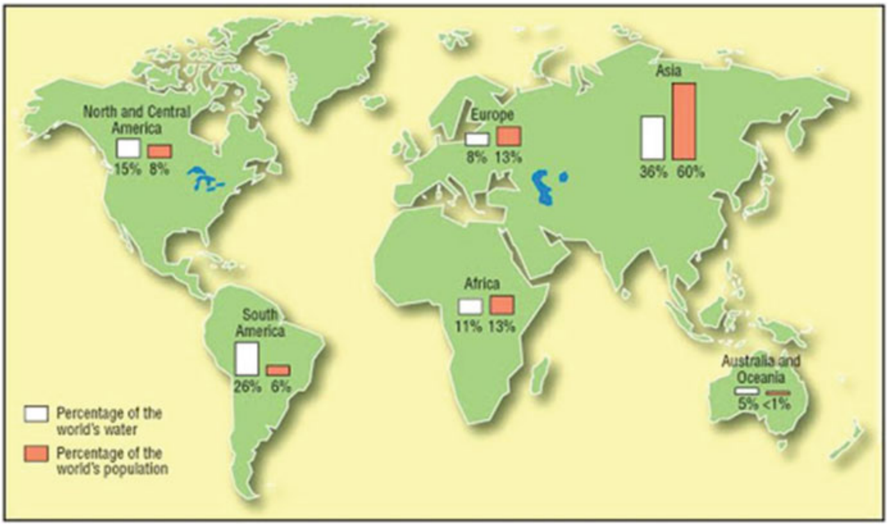

Fig. 3.1 Water availability versus population across the continents of the earth (UN 2003)

3.3 Access to Clean Drinking Water and Water Related Diseases

It is currently estimated that approximately one billion people lack access to a safe water supply. More recent data suggest that this is an underestimate. Without any intervention, by the year 2025, as much as two-thirds of the world's population will be living under serious water shortage conditions and one third of the population will be living in regions experiencing water scarcities. The year 2050 will see half of the world's population living in conditions of absolute water scarcity (Curry 2010; Ribolzi et al. 2011). Numerous countries are either suffering from intense water shortages or running the risk of being added to the water scarcity statistics.

The freshwater supplies of the world are deteriorating and there are numerous threats to maintaining supplies for the rapidly increasing human population. Both fresh surface water and groundwater resources are increasingly being depleted by mismanagement and by over-tapping, especially in countries where the natural water supply stores are less than the demand for water. Water pollution is also contributing to the depletion of freshwater supplies, with this problem being the greatest in countries where water regulations or enforcement is absent. The pollution of both surface and groundwater, limits the quality of water, especially in developing countries where approximately 95% of all untreated urban sewage is discharged directly into surface water bodies. The dumping of untreated urban sewage is not only occurring in developing countries. Some well-developed countries such as the USA are also guilty of this charge. Approximately 37% of all lakes in the USA are unfit for swimming in as a result of this type of pollution (UN 2003; Cassardo and Jones 2011; Ribolzi et al. 2011).

Human wastes, fertilisers, pesticides, eroded soil sediments, as well as untreated waste water from industries, are among the greatest sources of pollution. The pollution of surface water results not only in the water being unsuitable for human consumption but is also applicable to crops. By ignoring these problems and not addressing them, water shortages could be aggravated, humans and ecosystems be threatened and the levels of rivers and lakes could drop significantly, not only in developing countries but also in countries across the world (UN 2003; Cassardo and Jones 2011).

However, the increase in the human population is not the only cause of water scarcity. Political power, policies and socio-economic relations can also induce water scarcities as a result of unbalanced power relations, poverty and inequalities (Kummu et al. 2010; UNDP 2006). Political conflicts over water in areas such as the Middle East have strained international relations amongst these already water-starved nations. It is expected that the combination of political conflicts and the continuous increase in population will exacerbate these problems pertaining to water even further (O'Brien and Leichenko 2003; Cassardo and Jones 2011).

Furthermore, 20% of the world's potable water is lost from distribution pipes on account of inefficiencies (e.g. leaking pipes). Countries such as Bulgaria and Hungary have unacceptably large numbers as they lose 50% and 35% of potable water through pipe inefficiencies respectively. The Indian city of Bangalore loses approximately half of its pumped water even before it reaches the city's distribution systems. However, it is not only the developing nations that are feeling the effects of water shortages. Continued development and the intensification of the urbanisation process in developing countries, as well as the overall increase in the world's population, will cause a dramatic increase in water usage (Sikdar 2007; Ribolzi et al. 2011).

There is no substitute for water as it is an essential element for the survival of human beings and the environment. Industries and national economies are all dependent on this resource. The demand for already overcommitted national and international water resources in numerous countries has rapidly increased, especially in many of the world's largest cities. The result has been the ripple effect of disputes among riparian communities which eventually escalates into serious regional and international security issues (Shen et al. 2008; Frederiksen 2009).

The United Nations Secretary-General, Boutros Ghali, predicted in 1985 that the next Middle Eastern war would not be over politics or oil but rather over water. Even though this statement is still debated by numerous scholars, increasing scarcities owing to climate change, population growth, industrialisation, inefficient agricultural practices, and the degradation and maldistribution of water resources, could compound already tense interstate relations and could cause mass migrations of environmental refugees (Guslits 2011).

Thus, we can conclude that the present situation regarding water planning and management holds many challenges. The future thereof will become even more challenging as a result of an increase in the demands of the world's population and the increased impacts that will be associated with climate change. It is estimated that the world's population will increase by 2.5 billion people in 2050 to bring the world's total population to 9.2 billion. This increase in population is equivalent to the total number of people that were in the world in 1950 (UNEP 2007). Most of the growth in population will occur in the less-developed regions. Most of these regions are already the most severely affected by the lack of sanitation and drinking water services so that an increase in population will only aggravate the situation. South Africa is less confronted by a lack of sanitation and drinking water services however, the country is facing problems regarding inadequate sewage and waste water treatment plants due to the stagnation of the maintenance or upgrading of these facilities. The continued increase in the human population and economic growth have therefore placed immense pressure on these facilities and have caused inadequate treatment of sewage and waste water in some regions of the country.

3.4 Influences of Climate Change

Over the past couple of decades it has become apparent that humans have an influence on the climate system. Recent anthropogenic emissions of greenhouse gases are the highest that it has ever been and have led to climate changes which have been accompanied with widespread impacts on human and natural systems. IPCC (2014) states that it is very likely that the anthropogenic influence, particularly greenhouse gasses and stratospheric ozone depletion has led to detectable observed pattern of tropospheric warming and corresponding cooling of the lower stratosphere.

3.4.1 Observed Changes and/or Impacts

Changes in climate have caused impacts on natural and human systems across the globe. Impacts due to climate change are observed irrespective of its cause indicating the sensitivity of natural and human systems to changing climate. Impacts are strongest and most comprehensive on natural systems and should therefore be monitored more closely. IPCC (2014) states that it is likely that anthropogenic influences have affected the global water cycle since 1960. This has led to increased atmospheric moisture content, global changes in precipitation patterns over land as well as intensification of heavy precipitation over land regions.

The changes in climate in some cases is responsible for increases in the frequency or intensity of ecosystem disturbances such as droughts, windstorms, fires and pest outbreaks have been detected in many parts of the world. It should be highlighted that no globally homogeneous trend has been reported regarding the relationship between hydrology and temperature and precipitation. There is evidence of a coherent pattern of change in annual run off with some regions (especially northern latitudes) experiencing an increase (IPCC 2014).

It is concerning that groundwater levels of many aquifers around the world show a decreasing trend over the last few decades which will consequently place increasing pressure on regions which predominantly depend on groundwater resources. A decrease in groundwater levels of aquifers around the world are mainly due to pumping surpassing the recharge rates and not necessarily a climatic-related decrease of groundwater recharge.

In terms of global surface waters a consistent trend has been observed. In some cases some lake levels have increased (Mongolia and China, Xinjiang) mainly due to an increase in snow and ice melt, where other lake levels in China (Qinghai), Australia, Africa (Zimbabwe, Zambia and Malawi), North America (North Dakota) and Europe (central Italy) have experienced a decline due to the combined effects of drought, warming and anthropogenic activities (IPCC 2014).

The water quality of global water resources have also been influenced by changes in climate. Climate-related warming of waterbodies have been observed in recent decades which have led to changes in species composition, organism abundance, productivity and phenological shifts but also prolonged stratification with decreases in surface layer nutrient concentration and depletion of oxygen in deeper layers. However, due to dominant anthropogenic impacts not related to climate change, there is little evidence for consistent climate-related trends in other water quality parameters such as salinity, pathogens and nutrients in surface water and groundwater.

3.4.2 Future Changes in Water Availability

In terms of the future, the main climate drivers for water availability are temperature, precipitation and evaporative demand. Temperature will be a significant driver in snow-dominated basins as well as in coastal regions (sea level rise due to thermal expansion of water).

It is projected that the total annual river runoff over the land surface will increase, even though there are regions with significant increase and significant decrease in runoff. It is important to note that increased runoff can only fully utilized if adequate infrastructure is put in place to capture and store the extra water (IPCC 2014).

Climate change will affect groundwater recharge rates as well as the depths of groundwater tables. The knowledge of current recharge levels are poor across the globe and there has been little research done on the future impact of climate change on groundwater or the groundwater—surface water interactions. It is expected that groundwater will be affected by surface water flow regimes as many groundwaters both change into and are recharged from surface water (Doll et al. 2003; IPCC 2014). The increase in precipitation variability may be accompanied with a decrease in groundwater recharge in humid areas due to more frequent heavy precipitation events causing the infiltration capacity of the soil being exceeded more often. Increased precipitation variability in semi-arid and arid areas may however increase groundwater recharge due to only high intensity rainfalls are able to infiltrate fast enough before evaporating.

Globally the increases in groundwater recharge are expected to be less than the total run off according to the global hydrological model. It was computed that groundwater recharge will decrease by 2050 by more than 70% in North-Eastern Brazil, South Western Africa and the Southern rim of the Mediterranean Sea. However, this decrease may be overestimated as the study did not take the expected increase in variability of daily precipitation (Mimura et al. 2007).

More frequent heavy precipitation events are also projected over most regions throughout the twenty-first century and will consequently affect the risk of flash flooding and urban flooding. The increase in heavy precipitation events as well as the frequency increases over most areas may cause adverse effects on quality of surface and groundwater, lead to the contamination of water supply and in some cases relieve water scarcity (IPCC 2014; Mimura et al. 2007). However there is a degree of uncertainty in estimates on whether flood regimes can be positive or negative, once again highlighting the uncertainty still remaining in climate change impacts.

It is estimated that areas affected by drought will increase. A tendency for drying of mid-continental areas during summer may indicate a greater risk of droughts. The following is projected in terms of global drought frequency:

- An increase in the a proportion of land surface experiencing extreme drought at any one time (increase by 10- to 30-fold by 2090);
- An increase in the frequency of extreme drought events (increase by twofold by 2090); and
- An increase in mean drought duration (increase by sixfold by 2090)

The decrease in summer precipitation accompanied by rising temperatures which enhances evaporative demand in some regions such as Europe, will inevitably lead to both reduced summer soil moisture as well as more frequent and intense droughts. Regions which depend heavily on glacial melt water for their main dry season water supply will also an increased risk of drought as snowmelt is projected to become earlier and less abundant in the melt period. The hundreds of millions of people in China, Pakistan and India which depend on the snowmelt water from the Hindu Kush and Himalayas will therefore be adversely affected.

Water pollution is also projected to be exacerbated due to higher water temperatures, increased precipitation intensity, and longer periods of low flows. The increase of sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution is estimated. This will in turn promote algal blooms, and increase the bacterial and fungal content. This will, have adverse impacts on the world's different ecosystems, human health, and the reliability and operating costs of water systems (IPCC 2014).

Hydrological changes may therefore be positive in some aspects and negative in others. The projected increase of annual runoff may be accompanied with both in-stream and out-of-stream benefits for water users due to increasing renewable water resources, however it may simultaneously generate harm by increased flood risks. In addition, an increase in annual runoff may not lead to a beneficial increase in readily available water resources, if that additional runoff is concentrated during the high-flow season (Mimura et al. 2007). The increase of precipitation intensity may also result in periods of increased turbidity and nutrient pathogen loadings to surface water sources which will require substantial additional treatment and monitoring costs (Miller and Yates 2006).

With respect to global water availability and supply, it is very likely that the costs of climate change will outweigh the benefits globally due to that precipitation variability is very likely to increase, and more frequent floods and droughts are anticipated. The risk of droughts in snowmelt-fed basins in the low-flow season will increase. The impacts accompanied by floods and droughts may be alleviated/ mitigated by appropriate infrastructure investments and by changes in water and land use management. Water infrastructure, usage patterns and institutions are developed in the context of current conditions and do not consider these projected changes. Substantial change in the frequency of floods and droughts, or in the quantity and quality or seasonal timing of water availability, will require adjustments that may be costly, not only in monetary terms but also in terms of societal and ecological impacts, including the need to manage potential conflicts between different interest groups (Mimura et al. 2007).

3.4.3 Future Changes in Water Demand and Water Stress

The predicted higher temperatures and increased variability of precipitation will in general be accompanied with increased irrigation water demand even if the total precipitation during the growing season remains the same. It is predicted that irrigation requirements will increase from 1–3% by 2020 to 2–7% by 2070. The increase of domestic water demand and industrial water demand is likely to be less than 5% by 2050 in selected locations (Mote et al. 1999).

It should be highlighted that climate change would appear to reduce overall water stress at the global level using the per capita water availability indicator. This is mainly due to increases in runoff concentrated heavily in the most populous parts of the world, mainly in eastern and south-eastern Asia. However, given that this increased runoff occurs mainly during high-flow seasons (Arnell 2004), it may not alleviate dry-season problems if the extra water is not stored; and would not ease water stress in other regions of the world. The greater availability of water due to increased precipitation is the principal cause of decreasing water stress, while growing water withdrawals are the principal cause of increasing water stress (Alcamo et al. 2007).

Global estimates of the number of people living in areas with water stress therefore differ significantly between studies (Vörösmarty et al. 2000; Alcamo et al. 2003, 2007; Arnell 2004). Climate change is only one of many factors that influence future water stress; demographic, socio-economic and technological changes possibly play more important roles in most regions. The number of people living in water-stressed river basins would increase significantly mainly due to population growth projections.

3.5 Possible Water Conflicts

The most fundamental function of water as illustrated throughout this chapter is firstly as a prerequisite for life on Earth and secondly, as a commodity or economic resource. These two roles are constantly in conflict with each other in many areas of water usage. This has led to the exploitation of water through human activities which has in turn placed huge risks on aquatic ecosystems and the life that they support (Pimentel et al. 2010). Potential conflicts may therefore arise on a local and/or regional level between agriculture, domestic use, industry and the natural reserve. Different types of sub-national conflicts will therefore arise all over the world from water scarcity and be accompanied with immense socio-economic consequences.

3.5.1 California: Consequences of Severe Drought

Developed as well as developing countries will be affected by the increasing threat of water scarcity. Developed or rich countries such as the USA will not be able to avoid water supply problems due to the consequences of changes in climate as well as more frequent extreme weather events which create instability. A prime example of this within the USA has been the drought experienced by California in the past three years which has been attributed to the unusually low snowfall which has occurred across the state mainly due to increasing winter temperatures over the recent years. The current drought has been stated to be the worst in history (since 1895) and has started to affect the local and national economy since 2012 and significantly costing California US $2.7 billion in 2015. The drier conditions have primed the area's forests for larger and more frequent fires which can pose danger to people and property in their paths as well as other hazards such as landslide and floods (Poppick 2014; Aleem 2015; Kasler and Reese 2015).

These drier conditions will also lead to the deposition of soil and heavy metals into its already strained water resources, due to tree roots systems having a weakened ability to hold on to soil. The increase of turbidity of water will force water treatment facilities to increase their treatment costs to try and supply clean water the surrounding population which will have financial implications. The agricultural sector that uses 80% of the region's water has been affected the most. Farmers stand to lose US $810 million from keeping fields fallow, a further US

$453 million on pumping groundwater and likely to lose 17,000 agricultural jobs due to the drought (Aleem 2015; Kasler and Reese 2015).

Societal impacts of the drought have included the loss of jobs especially within the agricultural sector as well as an increase of food prices which have hit consumers hard this year. Political consequences have included that the government have had to request urban consumers to decrease water usage by 25%. Some inequality of access to water resources has arisen where 48% of wealthy homeowners with income above $100,000 have stated that it would be too difficult to conserve water. This has consequently led to heated debates within society whereby rich people do not mind paying a $100 fine for consuming too much and ordinary people are blamed for consuming too much. The drought has therefore given rise to an increase rise in class inequality as well as differing perspectives on water consumption. This has put immense pressure on the government to manage this precarious situation with a state historically characterized by injustice and racism with the allocation of water during the Gold Rush eras in the region (Aleem 2015; Johnson 2015; Kasler and Reese 2015).

Approximately 75% of the population depends on groundwater for a portion of their drinking water. The combined increase in pumping of groundwater for domestic and agricultural use has led to parts of the Central Valley subsiding due to the excessive and unsustainable abstraction of groundwater. Other neighbouring regions have also been affected due to the Central Valley Project, which supplies water to the San Joaquin Valley, only being able to supply 5% of the water that has been requested (Aleem 2015; Kasler and Reese 2015).

Food prices will also be affected due to the prolonged strain put on the agricultural sector. It is predicted that fruit prices will increase by 6% and vegetables by 3% nationwide. The state and federal governments have also had to give hundreds of millions of dollars in aid. Furthermore, the prolonged drought will cause the region to have to adapt and decrease their reliance on water. This will mean that the agricultural sector will have to decrease production of water-intensive crops and the public will need to invest in the instalment of water saving appliances in their homes (Mieszkowski 2014; Poppick 2014).

Numerous different conflicts have therefore developed within the region mainly due to the increasing competition for the region's depleting water resources. The region has a major challenge in terms of meeting the needs of water rights handed out over the last century. The state has handed out the rights to five times more surface water than the rivers in the region produce even in a normal year. The region's water rights system have struggled to adapt to twenty-first century realities of increasing water stress, changing climate and societal demands for water supply security and a healthy environment. This has consequently led to increasing conflicts between water users and confusion for water managers trying to establish whose supplies should be curtailed during the current drought. Conflicts have arisen between fellow farmers as well as the urban population and state drought regulators have gone on the offensive against some agricultural districts such as the Byron-Bethany Irrigation District in Byron with the issuing of fines accusing them of diverting water illegally. There has been increasing conflicts between the farming and fishing industries as well related to river flows needed for irrigating orchards and salmon spawning and urban users are starting to wade in since they've been told to decrease their water use by 25% (Kahn 2015; Kasler 2015; Skelton 2015).

The main conflict between farming and fishing industries has been exacerbated by drought causing the possible extinction of native fish species such as the delta smelt as well as threatening other native fish such as the longfin smelt, green sturgeon and winter-run Chinook salmon. Delta smelt populations have been declining for decades due to invasive predators, pollution, habitat loss and increased water exports to farms and cities. The drought has worsened conditions by reducing freshwater flows and raising water temperatures. This has consequently led to government regularly cutting water exports from the delta to protect the fish species and other threatened fish from being sucked into the giant pumps that send water south. Farmers feel that too much water has been wasted on these fish and scientists and environmentalists state that it needs protection due to it being an important indicator species for the delta's health. Some almond farmers have had to pull out some of their almond trees due to them not being able to obtain enough water for irrigation (Kahn 2015; Pedroncelli 2015).

The conflict between farmers and the urban population is centred around government ordering urban areas to cut their water use by 25%. Urban residents have consequently developed the perception that the agricultural sector is getting off easier and that this sector should be subject to more regulations however it should be noted that due to the drought farms have been allocated 0% share of the water from irrigation canals of the Central Valley Project and have led that half a million acres of farmland have had to be laid fallow in 2014 (Walker 2015).

Main critiques have been aimed at almond farmers who have continued to plant almond and other nut trees which require annual watering. California grows 80% of the world's almonds and is by far the biggest exporter of processed fruit and nuts. State officials have had to defend the agricultural industry and invoked globalization for the root cause as more than two thirds of almond crop is exported, much of it to China (Walker 2015). This has consequently also raised the debate of water efficiency in different farming sectors especially between almonds and beef or dairy production whereby it has been emphasized that it takes more than 100 gallons of water to produce an ounce of beef, compared with less than 50 for an ounce of almonds. The decrease in water use in the almond farming sector is mainly due to advances in irrigation technology which have lowered their water demand by a third. The conflict has extended to that opprobrium ought instead to be heaped on alfalfa hay, a low value crop sold as feed to dairies overseas, which takes up even more of the state's agricultural water supply than do almonds, 15% in recent years. Almond farmers further defend their stance by suggesting that almonds generate more jobs for the state economy per unit of water consumed than alfalfa, rice, beans or corn (Kahn 2015; Walker 2015). These conflicts and debates will continue within the region and will increase in intensity with the continuation of the drought as well as the persistent and increased impacts of water stress, changes in climate and the insatiable societal demands while trying to ensure a healthy environment.

Therefore, the drought has had widespread socio-economic effects within the California region. A positive outcome is that the drought has forced farmers to adopt more efficient water management technologies and practices that helped boost the revenue within limited available water and urban consumers have also been requested to cut their water use down by 25% by the government (Cooley et al. 2015; Johnson 2015). The adaptations made have consequently buffered the region's economy and job levels. Some of these adaptations and responses will build resilience, while others will have lasting and damaging consequences to the region's population, its ecosystems and future generations.

3.5.2 Sao Paulo: Water Shortages in a Metropolis

Brazil's biggest city, Sao Paulo, is described as an alpha global city and the most populous city and wealthiest state in the country. The city has the largest GDP in Latin America and the Southern Hemisphere. Sao Paulo consequently exerts strong regional influence in terms of commerce and finance but has recently been experiencing a record dry season. The persisting drought in combination with the insatiable demand for water by the growing population has led to severe drought and water shortages within the area. Even though the country produces 12% of the world's freshwater, and is termed as a water rich country, the Sao Paulo Metropolitan area finds itself in a water crisis with the main reservoir system being dangerously low. The 40 million people located within the metropolis are facing tougher water restrictions, pinched faucets and declining reservoirs (Ross 2015). The water crisis in the region has been attributed to persistent dry conditions, deteriorating city services and basic infrastructure as well as all rivers within the region being polluted by open sewers.

Concerns have been raised by leaders over a collapse of social order using the protests as well as looting which occurred in 2014 in the city of Itu as an example. Residents have become increasingly desperate to hoard water in the city. Consequently, local authorities fear rebellion as 11 million people are considering bringing in military control to avoid immense conflict over the very scarce resource (Davies 2014; Ross 2015).

Sao Paulo is Brazil's richest state and forms the core of its economic growth. If water and electricity generated by hydroelectric dams dwindles even further, the economy will suffer dire consequences in terms of financial and job losses. In 2015, the main water supply of the Sao Paulo metropolitan reached critical levels with only 5% storage in January and 15% at the end of the rainy season in March. The city is also characterized by high Non Revenue Water (NRW) statistic of 40%. This in combination with dwindling water supply in reservoirs has consequently led to rationing of water whereby some residents are left without water for a few days a week. Authorities have implemented a water conservation strategy by reducing pressure within pipes but this has cut off running water to millions of customers for hours—and in some cases days—depending on their location. Power cuts may also be implemented until water levels recover due to electricity being mainly produced by hydroelectric dams. Some rain has occurred within the region and poor districts have made a desperate attempt to store rainwater in open containers, jerry cans, plastic drink bottles and buckets to save it for the days of water shortage. Other citizens have drilled through their basement floors to extract water out of open wells (Davies 2014; Rigby 2015).

The rapid population growth within Sao Paulo has been accompanied with deteriorating city services as well as basic infrastructure that exacerbate the problem. All rivers within the region have become polluted by open sewers and have consequently led to induced water scarcity. The pollution of its rivers and wells has led to a dengue fever outbreak, which is being exacerbated by the limited access to safe water. The government consequently established impoverished ambulatories to attend the population with symptoms and attempted to educate the population regarding the disease however, all measures have proven to be inefficient to control the disease (Rigby 2015).

Officials in Sao Paulo have recently stated that the water shortage within the region is critical, with multimillion dollar emergency construction projects failing to ease the situation. The government has now permitted the suspension of licenses that allow agriculture, industry and other private concerns from drawing directly from the area of water supply as a radical measure to force a decrease in water abstraction (Rigby 2015). The growing population, insatiable water demands, the failure of city services and basic infrastructure as well as the lack of planning of water resources has led to the exacerbation of the region's worst drought in 80 years. The water shortages and drought have been accompanied by socio-economic losses and possible social unrest or conflict within the region due to growing competition for water.

Brazilian authorities have consequently made efforts to address water and poverty challenges within the region. These include pollution control and slum upgrading to address the major sewage pollution problem, reduction of water losses through the implementation of a 10 year programme focused on reducing NRW with the enhancement of infrastructure, combating fraud and illegal connections and improving staff training, the promotion of water re-use and conservation and lastly watershed protection initiatives which focus on increasing water yields with the improvement of water quality (Rigby 2015). It should be noted however that there has not been a comparable effort by municipalities to reduce water losses within the region. Buy-in from local authorities as well as the population is therefore imperative for Sao Paulo to improve its desperate water situation.

The water crisis currently experiencing by Sao Paulo has been attributed to government neglecting ecological management of water supply which has caused widespread water pollution causing a decrease in water supply due to water not being of an adequate standard, absence of proper maintenance of water service infrastructure which cause widespread water losses. The impact of these factors and possibly also the deforestation of the Amazon, has been exacerbated by the worst drought in eight decades within the region. More than 10 million people (suburban and slum areas) as well as businesses within the megacity have been suffering from water rationing whereby they are left without access to water from 09 h00 to 15 h00 on some days. It has been stated by the Brazilian water company that these residents should expect five days a week of restrictions and only two days of full service. This consequently has led some people to either flee to other regions within the country creating water refugees or drill their own wells to access groundwater which is unregulated and threatens underground supplies in terms of pollution. The building of resilient water systems have now been placed at the forefront in an attempt to decrease NRW in the most cost-effective manner as well as regulating well drilling to ensure the sustainability of groundwater supplies to create reserves for drought periods and a call for city water managers to adjust their risk formulas and take action sooner to avoid catastrophic outcomes (Postel 2015; Ward 2015). Even though the government have only recently (2015) attempted to address the problem, most damage has been done and it will now take a long period of time for the region to recover from the water crisis and get out of the predicament.

3.5.3 Nigeria: Growing Economy and the Cost of Crumbling Infrastructure

Nigeria, the most populous and largest economy country in Africa, is described as a country with abundant water resources, but it has begun to struggle with issues of water scarcity across all of its states with NRW of above 50% in the country. The water scarcity issue within the country is considered to be quite daunting as it is the eighth most populous nation in the world. It has a population of 152 million and less than 30% has access to safe drinking water. Approximately 63 million people lack access to safe drinking water and 111 million have no sanitation (Muta'aHellandendu 2012; Ibukun and Kay 2015). The water scarcity within the region has been attributed to insufficient water supply and sanitation services, high water losses due to inadequate and dilapidated water infrastructure as well as continued political unrest and corruption.

The growing population has put pressure on the agricultural sector to produce more food, have increased urbanization and standards of living have risen. The city of Lagos is especially experiencing strain in terms of an infrastructure shortfall due to thousands of people fleeing from rural poverty and Islamist insurgency. Water supply and sanitation services and infrastructure have become inadequate as it cannot support the large volumes of sewage. This has consequently led to widespread pollution of the region's water pollution and has been accompanied by water related diseases. The country is further inundated with vandalism of water pipes and erratic water flow due to daily electricity black outs. These factors accompanied by water pollution, political unrest and corruption have consequently led to a shortage of supply of freshwater (Gaedtke 2013; Ibukun and Kay 2015).

Lagos, the heart of Nigeria with a population of 21 million, has been experiencing insufficient water supply and sanitation services, high water losses due to inadequate and dilapidated water infrastructure as well as continued political unrest and corruption. The water crisis has also been attributed to the alleged privatisation of the state's water system, which it claims could cause a major hike in the cost of water in the state beyond what most people could afford. Approximately 90% of its households do not have access to water from the public water system. The Lagos State government has obtained loans from the World Bank, French Government and other donor agencies to fund water supply expansion schemes. These loans have not translated into improved water supply for residents as only 10% have access to the public water system. The quality of water can also not be guaranteed as some of the pipe are burst and lined near sewage tanks which consequently cause immense water related diseases and health problems within the city. Recently the Lagos State Water Cooperation had cut supply to some local communities in the state. Residents of Alapere community in Kosofe Local Government Area for example were said to be in search for alternative water supply and people stand in long queues before residential buildings with boreholes to obtain water (Taiwo-Oguntuase 2015; Olalemi 2016). This is now the second time since November 2015 that the region is experiencing a water crisis of this nature.

Even though the country has invested into the development of its water supplies, there is still a lack of access to safe sources of water supply and sanitation services such as the disposal of human waste, refuse and drainage facilities. As of 2007, some regions started to introduce public-private partnerships in the form of service contracts. The establishment of the National Water Supply and Sanitation Policy in 2000 as well as the encouragement of private-sector participation is aimed at the expansion and improvement of rural water supply systems and improving performance of service providers in urban centres. Even though sanitation access has gradually grown however piped sewage is almost totally absent. The lack of awareness, poverty, poor planning, poor funding, and poor implementation of hygiene programs by different agencies also hamper efforts to expand sanitation access (USAID 2007; Gaedtke 2013; Ibukun and Kay 2015).

For the country to have met the Millennium Development Goal for water supply by 2015, an annual investment of US $1.3 billion was needed however the country is currently only investing not more than US $0.5 billion annually into the water sector. Lack of proper investment in the rehabilitation of poorly maintained infrastructure has led to many health problems in rural areas due to polluted water and a shortage of water for daily hygiene. The lack of awareness of proper hygiene and sanitary behaviours have also attributed to sanitation-related diseases and worsened the problem. The lack of proper sanitation services, refuse and drainage facilities have caused sewage from slums to flow straight into the surrounding areas, and the lack of access to safe drinking water has led to people being diagnosed with typhoid, malaria, diarrhoea and cholera. It is estimated that the lack of running water killed more people in Nigeria in 2014 than Boko Haram did. The shortage of potable water led to 73,000 deaths and 11% of all under five deaths of the world occur in Nigeria due to diarrhoea related diseases (USAID 2007; Gaedtke 2013; Ibukun and Kay 2015).

Therefore, even though Nigeria is a water abundant country, it suffers from induced water scarcity, as the dominant part of the population does not have access to safe drinking water sanitation services. This accompanied with the deterioration of infrastructure as well as the infrastructure shortfall have led to widespread water pollution of both surface and ground water and water borne diseases and consequently affects the country's socio-economic growth as well as human and environmental health.

The world is therefore in an era of water shortages and water stress in both developed and developing regions. Extended droughts will be experienced by multiple regions and even though climate change may in some cases have positive effects in terms of runoff, it will mostly lead to severe and more intense water shortages across the globe. Even though the world has made progress in terms of providing its human population with access to clean drinking water, billions still lack access to this and proper sanitation facilities which combined with a decline in water availability will lead to even more severe water shortages and stress over the globe. Potential conflicts may therefore arise on a local and/or regional level between agriculture, domestic use, industry and the natural reserve. Different types of sub-national conflicts will therefore arise all over the world from water scarcity and be accompanied with immense socio-economic consequences.

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Part II
South Africa's and the Upper Vaal WMA's Freshwater Resources

Chapter 4
South Africa's Water Availability and Use

Unhindered water use has grown globally at twice the rate of population growth in the twentieth century and has caused some regions to be no longer able to deliver reliable water services. Water scarcity within South Africa is a reality and the continued demographic pressure, rate of economic development, high rates of urbanization and pollution will put unprecedented pressure on the country's water resources. It is estimated that the country's total requirements for water use will double over the next 30 years. Major industrial development and urban settlement have taken place in regions where water resources are not readily available and have resulted in substantial potential impacts on the quality of water in the country which is already limited in terms of supply. South Africa is currently facing a multi-faceted water crisis. The mismatch between water supply and water demand, the theft of water resources, a deteriorating infrastructure, the loss of essential skills, a strangling educational pipeline, demand management failure, as well as deterioration in the quality of the water, are all potential threats and key concerns that could lead to the fact that the country is experiencing a water crisis. Focus is placed on both the country's and Upper Vaal WMA water availability and in conclusion the influence of the main water use sectors on the country's limited water supply in terms of water abstraction and water losses.

4.1 Introduction

Unhindered water use has grown globally at twice the rate of population growth in the twentieth century and has caused some regions to be no longer able to deliver reliable water services. Water scarcity within South Africa is a reality and the continued demographic pressure, rate of economic development, high rates of urbanization and pollution will put unprecedented pressure on the country's water resources.

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_4

South Africa's water resources are scarce and unevenly distributed. Even though water is renewable, it is a finite resource which requires good management and conservation. It is estimated that the country's total requirements for water use will double over the next 30 years. Major industrial development and urban settlement have taken place in regions where water resources are not readily available and have resulted in substantial potential impacts on the quality of water in the country which is already limited in terms of supply (Ashton and Haasbroek 2002).

4.2 Water Availability

South Africa receives an annual average rainfall of 497 mm, far lower than the world average of 860 mm, so that the country can be described as semi-arid. The rainfall is highly seasonal, unevenly distributed, and 65% of the country receives less than 500 mm per year (Ashton and Haasbroek 2002). Rainfall is concentrated mainly along the narrow southern and eastern coastal areas and the amount declines sharply from east to west and from south to north. The annual average potential evaporation rate exceeds the annual average rainfall by approximately 360% and owing to this, only 8% of the rainfall is converted into usable runoff. As a result, South Africa is rated as one of the 20 most water-deficient countries in the world (Mckenzie and Bhagwan 1999; Metcalf-Wallach 2007).

The mean annual runoff of South Africa is estimated to be 49 billion m^3 per annum however only 10.24 billion m^3 per annum is available in high assurance. Approximately 9.5 billion m^3 per annum is required to satisfy the ecological reserve (rivers, dams, wetlands and estuaries) and 472 million m^3 per annum is required for the human reserve (domestic component of 25 L per person per day) which totals 11% of the total domestic water use. Many rural settlements still have insufficient water resources to meet their basic water demands and further surface and groundwater developments are required (NEPAD 2013; DWS 2014).

The Upper Vaal WMA is a very important water management area in South Africa from a water resource management perspective as it contributes significantly to the country's GDP. In fact, the Vaal River has been described as the 'workhorse river' of the country. This river system supports 60% of South Africa's economic activities and can thus be described as the lifeblood feeding the economic hub of the country. The need for water in this region, namely the Johannesburg-Pretoria-Witwatersrand-Vereeniging area, is so significant that strict water control measures have been introduced (DWS 2004a; Dzwairo et al. 2011; Wepener et al. 2011).

In terms of the Upper Vaal WMA, the climate is fairly uniform with rainfall ranging from 800 mm per annum in the east to 600 mm in the west. The natural mean annual runoff for the entire WMA is approximately 2400 mm per annum, with the region located upstream of the Vaal Dam contributing approximately 1100 mm per annum. The total surface water yield in the year 2000 for the entire WMA was estimated at 600 million m^3 per annum, with a total local yield of approximately 1100 million m^3 per annum. The total local demand for water for the whole WMA was estimated at 1050 million m^3 per annum, with the urban sector requiring the most, followed by the mining and bulk industrial sectors, the agricultural, power generation and the rural sectors (DWS 2004a). With further development on a regional and a national scale, increased pressure will be brought to bear upon these allocated water resources with the result that careful management will be required to enforce strict water controls.

Large amounts of water are transferred to the Upper Orange catchment via Lesotho, while three other WMAs are dependent on the water from the Upper Vaal WMA. The water resources of the Upper Vaal WMA are fully developed and future growth will have to be met through increased water transfers from the Thukela WMA, as well as from the Orange River and the Lesotho or Upper Orange WMA. It should be noted, however, that these water transfers not only have an impact on the mentioned few recipients but also involve a total of ten WMAs and also South Africa's neighbouring countries. The quantity and quality of the water from the Upper Vaal WMA is thus of vital importance on a regional, national and international scale (DWS 2004a; Dzwairo et al. 2011).

In order to meet the country's growing water demands, the surface water resources have therefore been well developed and supply most of South Africa's urban, industrial and irrigation needs. The country has 569 dams with a total capacity of 32,400 million m^3. These dams capture approximately 70% of the total mean annual runoff. However, the available water supply of the country is reduced by evaporation from the dams, the demands of the sugar-cane farming industry, as well as commercial afforestation to name but a few. Furthermore, an estimated 8% of the country's water resources are lost through evaporation from storage dams, as well as from the country's rivers and 6% as a result of farming activities. On the other hand, 66% of the country's mean annual runoff remains in the country's water store. Even though the country has a well-developed surface water infrastructure, ten of the nineteen water management areas of the country could not meet the demand for water in 2000 which resulted in the development of numerous transfer schemes between the respective catchment areas and between the respective water management areas (Department of Energy 2009; Muller et al. 2009; CSIR 2010).

South Africa is currently facing a multi-faceted water crisis. The mismatch between water supply and water demand, the theft of water resources, a deteriorating infrastructure, the loss of essential skills, a strangling educational pipeline, demand management failure, as well as a deterioration in the quality of the water, are all potential threats and key concerns that could lead to the fact that the country is experiencing a water crisis (Herold 2009). Water has thus been recognised in South Africa as a strategic national resource which is not equitably distributed—neither in temporal nor in geographical terms.

Owing to the growing population and her expanding economy, South Africa's current freshwater resource status is described as being under immense pressure. Practically all of South Africa's freshwater resources, including those from rivers, man-made dams and groundwater sources, had already been fully allocated by

2005. In the light of estimates made concerning the future demand for water, it has been predicted that South Africa will suffer serious water shortages in 2020 (Levite and Sammy 2002; Reddy 2002; Oberholster and Ashton 2008; Huizenga 2011; Pitman 2011).

4.3 Water Use and Losses Within the Country

Current usage is estimated to be between 15 and 16 billion m^3 per annum. Without effective metering and billing, consumption in urban and rural areas could rise to over 7.3 billion m^3 per annum resulting in an increase in total water use of close on 20 billion m^3 per annum. Therefore, current usage can be seen to exceed reliable yield and in the event of a drought year it is likely that the country will experience water restrictions at a large scale (NEPAD 2013). This has shown to be accurate during the current drought (2015–2016) which the country is experiencing.

Approximately 95% of the country's resources had been allocated in 2005 and the water quality of these resources has also declined. Increased pollution has been caused by industries, urbanization, afforestation, mining, agriculture and power generation (Ashton et al. 2008). Other factors such as outdated and inadequate water treatment and sewage treatment plant infrastructure and unskilled operators have also exacerbated the situation (CSIR 2010; DWS 2014).

The quality of the allocated water from South Africa's freshwater bodies has declined as a result of increased pollution caused by substantial growth in industry, urbanisation, afforestation, mining, agriculture and power generation (Ashton et al. 2008). Given the current and anticipated future growth rates of the population, and trends in socio-economic development, it has been estimated that South Africa's freshwater resources will be unable to sustain the current patterns of water usage and discharge into the near future (refer to Table 4.1).

According to estimates, the country's freshwater resources are currently fully depleted and will not be able to meet the demands of the population and industry by the year 2030 (NCCC 1998; Kundzewicz and Krysanova 2010). Furthermore, even if the country's population growth were to remain static or to increase only slightly, pollutants from various human activities will continue to accumulate in her freshwater systems.

To improve her freshwater resources, the country needs to improve her management approaches and also her treatment technologies (Oberholster and Ashton 2008; King et al. 2009; Pitman 2011). The calculations for the country's future water consumption do not take account of all the water used by the informal farming sector and rural communities, nor the water that is needed for shared water courses and ecosystem maintenance (SADC 1995). These amounts could increase the volumes by 20–30% above the original estimates (Pallet 1997; Kundzewicz and Krysanova 2010).

If these estimates are considered to be valid, the deduction can be made that the effective limit of South Africa's exploitable resources will be reached within

Table 4.1 Water requirements as measured in 1996 and the projected water requirements for 2030 by the main water usage sectors in South Africa (Basson et al. 1997)

Sector	1996		2030		Volume increase (%)
	Volume (10^6 m^3/year)	Sector use (%)	Volume (10^6 m^3/year)	Sector use (%)	
Urban and domestic use	2171	10	6936	23	220
Mining and industrial use	1598	8	3380	11	112
Irrigation and afforestation	12,344	62	15,874	52	29
Environmental	3932	20	4225	14	8
Total	20,045	100	30,415	100	52

15–30 years, as estimated in 1997 (Basson et al. 1997; Pallet 1997; Ashton 1999; Kundzewicz and Krysanova 2010). Figure 4.1 shows the highest and lowest projections, with existing and new technologies, for water demand in the country as against available surface water, groundwater and recycled water.

Thus, the South African Department of Water and Sanitation have developed several guidelines in order to ensure that, depending on water usage, the quality of the water is of the correct standard. Water quality is negatively affected by numerous anthropogenic activities, and by either point or diffuse source pollutants. South Africa's freshwater resources are fully allocated with the result that the water quality of these resources needs to be effectively managed and maintained.

To avert a predicament, water demand needs to be managed in conjunction with water conservation to ensure that all sectors improve their water use efficiency for the development of potential water savings. Water demand needs to focus on reducing water losses, increasing water productivity and re-allocating water resources but also take water pollution into account. Focus therefore needs to be placed on minimizing non-productive losses from water systems and preventing degradation of water sources. As a conclusion to this chapter, a focus will be placed upon the share of water loss for each main sector and the potential water savings for each by looking at the main types of water losses and possible incorporation of water efficiency measures due to the high Non Revenue Water (NRW) figure the country is characterized by.

4.3.1 Agricultural Water Use and Losses

The agricultural sector accounts for an estimated 62% of water utilization in South Africa even though only 12% of the landmass is considered arable and only 3% truly fertile. This sector contributes significantly to the country's economy as well as to rural development. It assures food security and contributes to employment opportunities throughout the food production chain which may include food

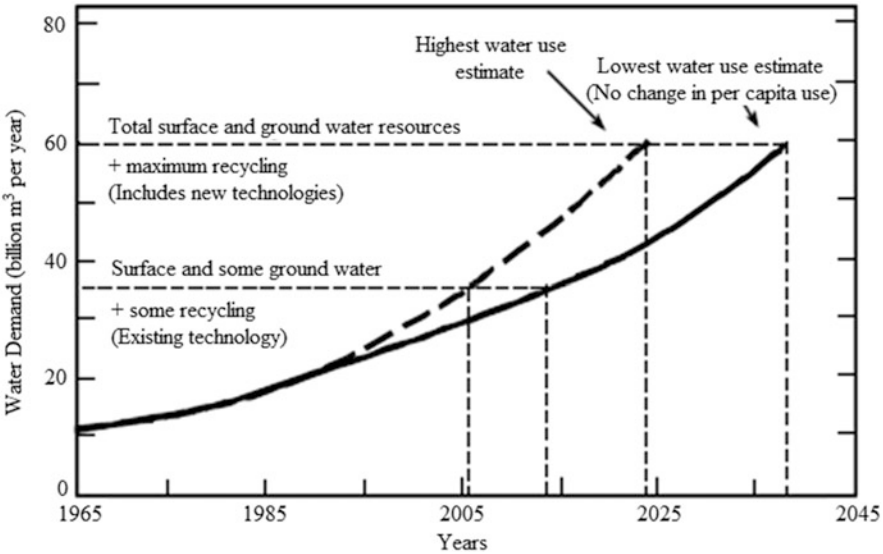

Fig. 4.1 The highest and lowest projections, with existing and new technologies, for water demand in the country as against available surface water, ground water and recycled water (redrawn from Ashton 1999)

processing activities in some instances (NEPAD 2013; DWS 2014; OSEC 2011; Oberholster and Botha 2014).

Only 1.5% of South Africa's land is under irrigation, demanding 60% of the country's water supply. Approximately 8.5% is irrigated from ground water and 91.5% irrigated from surface water. Water sources for agricultural purposes therefore include both surface and groundwater with surface water being the main source for the sector. Main types of water use within the sector include irrigation as well as stock watering (<1.5%) (DWS 2004a). Subsistence farming requires relatively low amounts of water as water is mostly carried manually from the water source. The commercial farming sector on the other hand uses far higher volumes due to mechanized irrigation systems. Most potential for an increase in water efficiency would therefore be by focusing on irrigation water use in the sector. Different types of irrigation and their use include localized irrigation, 12%; surface irrigation, 33%; and sprinkler irrigation, 55% (CSIR 2010; NEPAD 2013).

The discharge of water from agricultural practices can take different routes which include through evaporation, absorbing by plants while the rest may leave fields either by surface runoff or by infiltration into aquifers. The runoff as well as infiltration often contains fertilisers and pesticides which are used and will consequently pollute surface water bodies as well as groundwater aquifers. The degradation of freshwater resources through agriculture takes place through non-point source pollution which reduces the overall quality of water for future uses both in terms of surface and groundwater (CSIR 2010; NEPAD 2013; GCIS 2015).

The constant increase in the population has put pressure on the agricultural sector to produce more in order to ensure food security. The intensification of farming practices especially in terms of commercial farming have led to an increase in water abstraction which have led to a rise in growing environmental problems which may include lower ground water and river flows, disappearance of wetlands related to the implementation of drainage systems, oxygen deficits in rivers leading to possible extinction of species of flora and fauna, the gradual salinization of ground water in coastal areas, environmental problems from the construction of dams as well as the diversion of water courses for irrigation purposes and lastly, increased leaching of nitrate and pesticides from agricultural land polluting both groundwater and surface waters (CSIR 2010; NEPAD 2013; GCIS 2015). Some water is also lost through unauthorized use for agricultural purposes and is included in the NRW statistic of 39%.

Multiple irrigation agricultural schemes experience estimated water losses between 35 and 45% due to most of these schemes falling into a state of disrepair and some having exceeded their economic lifespan. Water losses within the agricultural sector are mainly attributed to run off losses, inefficient irrigation techniques and leakages (conveyance losses), wasteful field application methods and the cultivation of thirsty crops not suited to the environment. Other factors which also contribute include improper irrigation scheduling, soil type and soil preparation (Colvin 2015).

Alien invasive plants also have a big impact on water resources due to them using twice the amount of water than indigenous plants in some areas. Alien invasive plant species are estimated to consume about 3 billion litres of water a year of South Africa's supply (WWF 2004). The clearing of alien invasive species is a cost-effective measure which can be implemented on farms to reduce this type of water loss.

Furthermore, not all water abstracted through conventional irrigation methods reaches the root systems and plants. Approximately 35% of unaccounted proportions of irrigation water return to river systems by overland flow and return seepage which can be nutrient enriched and polluted with herbicides, pesticides and other pollutants which detrimentally affect the water quality of the receiving river systems and possible salinization, eutrophication and sedimentation downstream. Unsustainable water use within the agricultural sector can therefore also be accompanied with a change in water table and/or depleting groundwater supplies as well as environmental degradation in the form of an increase of soil salinity, wash pollutant and sediment into surrounding water bodies caused mainly by excessive irrigation (WWF 2004; CSIR 2010; NEPAD 2013; GCIS 2015).

4.3.2 Industrial Water Use and Losses

The mining and industry sector is estimated to account for 16% and the energy sector (power generation) 2% of South Africa's water utilization. Mining operations account for approximately 3% of water withdrawn and is one of the main sectors responsible for water degradation (CSIR 2010). The diversity of industry and different mining sectors however cause the water use in these sectors to be highly varied and obtain their water from Bulk schemes or municipalities.

Mining within the country has in many ways formed the foundation of its economy and a number of factors drive and influence its demand. It is expected that the mining sector will expand (coal and platinum) and may unavoidably be located in water scarce catchments. In terms of industries, this sector ranges from the processing of agricultural and forestry products, construction, manufacturing (iron and steel), food processing, textiles, commercial industries to tourism-related industries (CSIR 2010; NEPAD 2013).

Water supply to these sectors either occur through abstracting water from a water resource regulated in terms of the National Water Act (mines, power stations and some industries) or those serviced by water providers (water supply and wastewater treatment) mainly commercial users and most industries. Industries use water in either their main or secondary operations (i.e. office buildings). Water loss within these sectors mainly occurs due to leakages as a result of ill maintained or inadequate water supply infrastructure. Further water losses, such as in the case of the agricultural sector, occur through pollution of the surrounding waterbodies by waste water and dumping of waste materials. The occurrence of acid mine drainage within the Gauteng, Mpumalanga Provinces and other mining areas is especially of high concern due to the large scale damaging consequences it has had in all spheres. The estimated percentage of water loss for this sector is included in the total NRW percentage of 39% (CSIR 2010; NEPAD 2013).

Water plays a dominant role in mineral processing and is required for hydrometallurgical processes. It is also made use of in pyrometallurgical processes for cooling and other parts of the process. Significant amounts of water are also required for dust control on roads and waste dumps. Non contaminated, low quality industrial and mine water can be used for processes while high quality potable water is required for domestic purposes in the administration buildings and camps. The effect of mining on water quality can be severe and the contamination of water resources consequently means that there is less water available for human consumption and environmental processes (ICMM 2012). Water in these sectors are therefore discharged through runoff waste water from some activities, possible evaporation such as in the case of dust control activities as well as effluents or waste water discharge.

Power generation requires 2% of South Africa's water supply. This may seem like a low consumption however it is relatively high due to the country only having few power stations. Most of the power stations were designed to have high water consumption in the form of wet-cooled and wet-ashing power stations (NEPAD 2013; Oberholster and Botha 2014).

4.3.3 Municipal/Domestic Water Use and Losses

Residential water use is just one component of the complete urban water-use profile which also includes industrial, business or commercial, institutional and municipal water use as well as water loss (Hall and Watson 2000). An analysis of water use in the City of Cape Town, found that residential water consumers contributed to almost 90% towards the total number of water users and about 55% to the total water-use volume (Jacobs et al. 2007). A focus on residential customers therefore includes the most notable part of urban water use.

Water is fed to a property via a metered water connection and pressurized water pipes. On the property the water is used by the consumer to meet various desired needs, some of which are for indoor demands and others to meet outdoor demands. Each of the individual water needs could be viewed as an end-use of water. Literature is in broad agreement that the bath, shower, toilet and washing machine combined contribute about 80% to the total indoor water use in a typical domestic household. Garden water demand contributes most to water demand at residential properties, that is if a garden is present on the property and is irrigated (Jacobs 2008).

A basic household water supply is 25 L per person per day or at least 6000 L per household per day with the following criteria according to government policy:

- Minimum flow rate of not less than 10 L/min;
- A standpipe within 200 m of a household;
- Interruptions of less than 48 h and cumulative interruptions during the year of less than 15 days; and
- At potable standard

Approximately, 91% of the population having access to basic service levels. The domestic use water requirement of the country accounts for 30%. This percentage is divided into 25% for the country's urban areas and 5% for rural areas. The average water use therefore differs from high and medium income areas to low income areas. The demand is likely to increase in this sector due to population growth, increased percentage of the population having access to water services by addressing the backlog and expected improvement in the standard of living resulting in an increase of per capita water consumption (CSIR 2010). Average daily water demand for domestic users (single residential stands) is based on stand area. The "Red Book" contains guidelines with regards to non-domestic water demand. It is recommended that non-domestic water demands should be based on field measurements as it is extremely difficult to estimate non-domestic demand (CSIR 2003).

The urban water use sector can be divided into the following: 20% gardening; 30% household; 12% industrial; 10% commercial; 2% municipal and 26% unaccounted for water. Looking specifically at middle and high income households, the average monthly water use is estimated at 46 kL per property per month. In these areas the actual water use is greatly dependent on the incidence of swimming pools and garden irrigation (CSIR 2010).

It is however concerning that StatsSA's general household survey indicates that little growth has occurred in terms of the access to water infrastructure over 2006–2009 mainly due to the failure of existing infrastructure as a result of lack of operation and maintenance plans/programmes (StatsSA 2014).

The NRW figure for the country is 39%. Importantly, rural municipalities have a NRW of 72.5% while metropolitan/urban municipalities an estimated 35.3% water loss. The high amount of water loss present at rural municipalities is attributed to poorer infrastructure and them having less resources to recover costs (KPMG 2014). The greatest issue of concern in these low income areas is unbilled authorized consumption due to underestimation of water use in these areas as tariffs are based on assumed meter readings. This leads to significantly higher water use than the deemed consumption as there is no water efficiency incentive. Category A municipalities (metros) achieved NRW levels of around 34.3% compared to the water losses of 72.5% (on average) achieved by B4 (small) municipalities. NRW levels of mid-sized municipalities range from 30.5 to 41.3% on average (DWS 2004b; Jacobs 2008).

The greatest source of water loss in middle and high income areas is through physical leakage rather than unbilled use. Physical leakage in the reticulation system is the main issue in these areas which need to be addressed through undertaking leakage control at regular intervals as metering, billing and payment is generally under control in these areas. Approximately 31% of the total water supplied does not reach the customer due to leakage (Hay et al. 2012; KPMG 2014; Mckenzie 2014).

Presently, municipalities are finding themselves in crisis mode and the lack of information available from more than half of all municipalities illustrate that half are not even aware that they have a problem. In terms of record keeping it is estimated that of the 61% of South African municipalities (no response received from 39%), 18% have poor record keeping, 30% has worthless records and 13% no records at all. This is of major concern and the situation is exacerbated by many municipalities lacking basic meter readings which mean they don't even know that they have a problem (NEPAD 2013).

In the meantime the percentage of the population with access to improved water supply has risen from 83% in 1990 to 91% in 2008. However, due to compromised water quality and intermittent supply caused by poor maintenance has made this improved access meaningless for a variety of places due to that water cannot be used as a result of it being of an unacceptable standard (Blaine 2013).

Unbilled authorized consumption is estimated at 5% and apparent losses at 20% of total water losses. It should be noted that apparent losses vary considerably between municipalities due to different ages of infrastructure and the various meter replacement policies adopted by each. Apparent losses therefore range as high as 50% water loss and as low as 5% in others (Wegelin et al. 2011).

These sectors therefore influence the country's as well as the Upper Vaal WMA's available water resources through abstraction but also water quality and water losses.

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Chapter 5
The Upper Vaal WMA

The Upper Vaal WMA extends over four provinces, namely Gauteng, North-West, Mpumalanga, as well as Free State province. It does not directly share any rivers with neighbouring countries. Large quantities of water are transferred into the Upper Vaal WMA from the Lesotho Highlands Project, as well as through catchment transfers to and from neighbouring WMAs. The Vaal River is considered to be the main water source for the central industrial, mining and metropolitan regions in South Africa, and also serves Gauteng, Mpumalanga, Free State, Limpopo, North-West, as well as the Northern Cape provinces. The Upper Vaal WMA covers a relatively large area and is very important to the South African economy and for future development. The natural landscape has been transformed and manipulated physically and chemically in order to meet society's needs. The changes of land cover and land use have consequently been accompanied by various impacts on the specific region's hydrological responses and ultimately its water resources. The large variety of sectors have been accompanied with multiple major water-related problems which could in the near future have detrimental effects on the country's socio-economic growth as well as the ecological health of the surrounding environment. Focus is placed on the description of the Upper Vaal WMA and its water resources.

5.1 Introduction

South Africa was divided into 19 WMAs in 1999. However, these boundaries do not correlate with South Africa's administrative boundaries. Factors that were taken into consideration were institutional efficiency, the financial self-sufficiency of the water consumers, the centres or locations of economic activity, social development patterns, the distribution of water resource infrastructures, and lastly, the centres of water-related expertise for future assistance (DWS 2004a).

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Springer Water, DOI 10.1007/978-3-319-49502-6_5

Fig. 5.1 Water management areas and the provincial boundaries of South Africa (Oosthuizen 2002)

The Upper Vaal WMA, as listed and defined by the DWS, is one of the 19 WMAs in South Africa. The Upper Vaal WMA is listed as number 8 in Fig. 5.1.

The Upper Vaal WMA extends over four provinces, namely Gauteng, North-West, Mpumalanga, as well as Free State province. It does not directly share any rivers with neighbouring countries. However, large quantities of water are transferred into the Upper Vaal WMA from the Lesotho Highlands Project, as well as through catchment transfers to and from neighbouring WMAs such as the Thukela. A description of the main catchment areas as well as sub-catchments of the Upper Vaal WMA now follows.

5.2 Upper Vaal Catchment Areas

The Upper Vaal WMA is part of the Vaal Catchment area, which also includes the Middle and Lower Vaal WMAs (DWS 2011). As indicated in Fig. 5.2, the Orange/Vaal River Basin covers an area of approximately 964,000 km^2 and extends over four countries, namely South Africa, Lesotho, Botswana and Namibia. Approximately 600,000 km^2 of the Orange/Vaal River Basin falls within South Africa and for the most part extends across the central region, which represents almost half of the country's surface area (Pitman and Lauchli 2002). The Vaal River is located

Fig. 5.2 The Orange/Vaal River Basin, which extends across South Africa, Lesotho, Botswana and Namibia (modified from DWS 1997; Kneidinger 2007)

within this basin and is the largest tributary of the Orange River, which eventually flows out into the Atlantic Ocean at Alexander Bay.

The Vaal River has a total catchment area of approximately 192,000 km^2. The source of the river is located on the western slopes of the Drakensberg escarpment in Mpumalanga, east of Johannesburg. The river flows approximately 1200 km in a west-south-westerly direction across the interior plateau to its confluence with the Orange River near Douglas, southwest of Kimberley in the Northern Cape (Basson 1978; Braune and Rogers 1987; DWS 1997). The main tributaries of the Vaal River drain the Drakensberg in the east, the Witwatersrand in the north and the Maluti Mountains in the south. The river also forms the provincial border between Gauteng, Mpumalanga and North-West along its northern bank, while its southern bank borders on Free State province (Braune and Rogers 1987).

The Vaal River is considered to be the main water source for the central industrial, mining and metropolitan regions in South Africa, and also serves Gauteng, Mpumalanga, Free State, Limpopo, North-West, as well as the Northern Cape provinces (Bertasso 2004; DWS 2004b). As a result, the Vaal River is frequently intercepted by numerous dams and small weirs which cause the flow into the Orange River to be sporadic. The major dams within the Vaal River catchment area include Grootdraai, Sterkfontein, Vaal, Vaal Barrage, Koppies, Bloemhof, Vaal–Harts and the Douglas Weir. The Vaal Dam is the most important regulator of water to the Vaal River (Braune and Rogers 1987).

The Upper Vaal WMA includes towns as far afield as Breyton, Harrismith, Johannesburg and Potchefstroom. It is divided into three main secondary catchments, namely the Vaal River (C1), the Wilge River (C8), the Vaal River Barrage and Kromdraai (C2) (includes the Mooi River catchment and also the Vaal River Barrage Reservoir), as well as tertiary catchments within these—as illustrated in Fig. 5.3. These catchments are divided into tertiary drainage regions as indicated in Fig. 5.3 and described in Table 5.1.

The Vaal Dam catchment, which is made up of two main sub-catchments, namely the Vaal River and the Wilge River, herewith referred to as secondary catchments (Gyedu-Ababio and van Wyk 2004), with their accompanying tertiary catchments, as listed in Table 5.1, covers an area of approximately 39,000 km^2. The Vaal Dam is fed by the Klip, Vaal, Liebenbergsvlei, Wilge, and lastly, the Waterval Rivers as illustrated in Fig. 5.4. The Klip River has its source close to the town of Memel, situated in the Drakensberg highlands, which separate the Wilge from the Vaal River catchment area. The Liebenbergsvlei River originates in the Drakensberg mountains in the vicinity of Clarens and close to Bethlehem in Free State province. The Wilge River has its source in the Drakensberg Mountains beyond Harrismith, and its

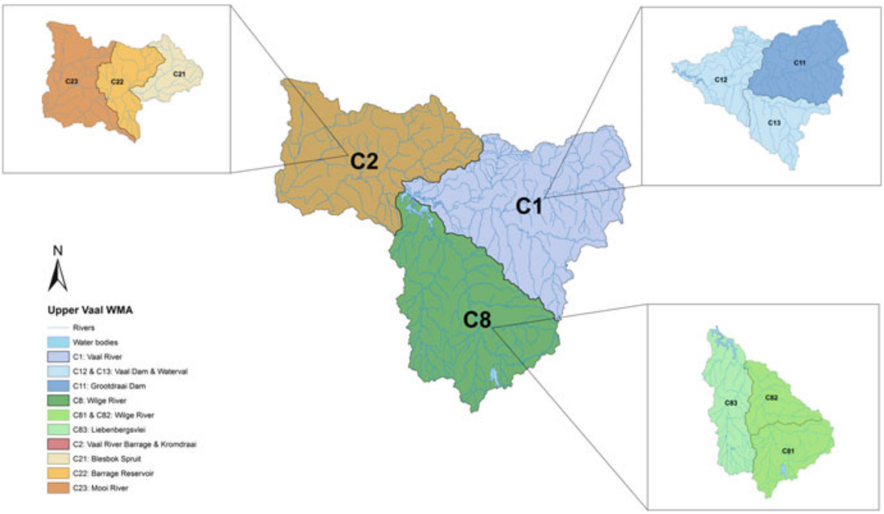


Fig. 5.3 Secondary and tertiary catchments of the Upper Vaal WMA

Table 5.1 Secondary and tertiary catchments according to the DWS drainage region categories

Secondary catchment	Tertiary catchment
C1: Vaal River	C11: Grootdraai Dam
	C12 & C13: Vaal Dam and Waterval
C8: Wilge River	C81 & C82: Wilge River
	C83: Liebenbergsvlei
C2: Vaal River Barrage and Kromdraai	C21: Blesbok Spruit
	C22: Barrage Reservoir/Vaal River Barrage
	C23: Mooi River, Loop Spruit and Wonderfontein Spruit

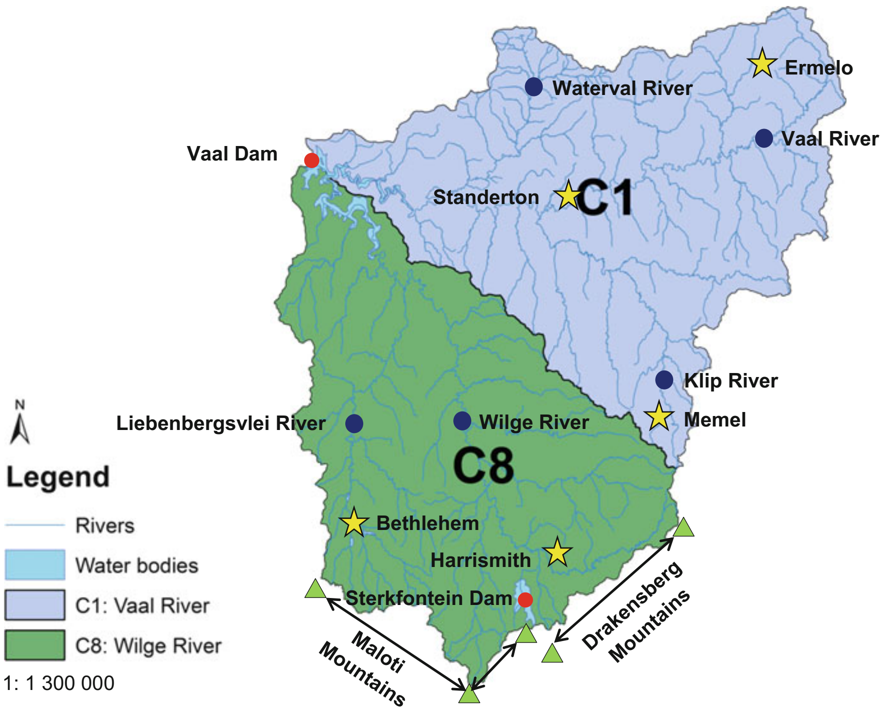


Fig. 5.4 Vaal Dam secondary catchment with major dams, rivers and other landmarks

tributary, the Namahadi River, has its source high in the Maloti Mountains, close to Golden Gate National Park in the Eastern Free State (DWS 2003a).

The Vaal River Barrage catchment, located downstream of the Vaal Dam, covers an area of approximately 900 km^2, which amounts to a mere 4.5% of the catchment area of the Vaal River. This catchment occurs in a portion of Gauteng Province, accommodating an estimated population of 11 million residents. The Vaal River Barrage catchment includes the heavily populated and industrialised regions of

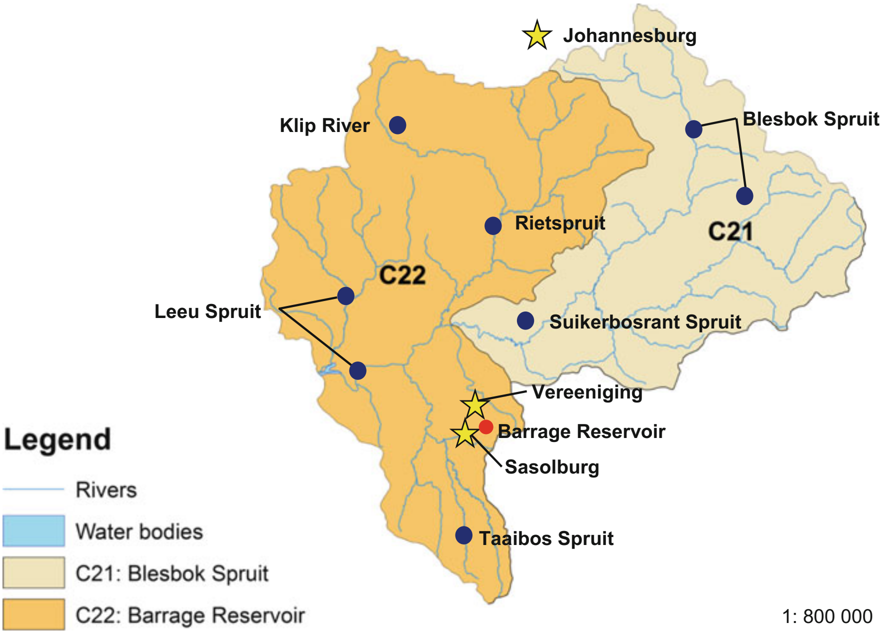


Fig. 5.5 Vaal River Barrage secondary catchment with major dams, rivers and urban landmarks

Johannesburg, Vereeniging and Sasolburg, and can be divided into five sub-catchments known as the Barrage Reservoir, Blesbok Spruit and Suikerbosrant Spruit, Klip River, Leeu Spruit and Taaibos Spruit, and lastly, the Rietspruit area as illustrated in Fig. 5.5. As a result of the densely populated areas in its vicinity, the Vaal River Barrage catchment area is threatened by a number of pollution problems (DWS 2003a; Tempelhoff et al. 2007). The Vaal River Barrage is therefore divided into two main tertiary catchments namely the Barrage Reservoir (referred to in this thesis as the Vaal River Barrage tertiary catchment) and Blesbok Spruit catchments.

The Blesbok Spruit catchment, as shown in Fig. 5.5, is located in the eastern region of the Gauteng Province, South Africa, within the Upper Vaal WMA. More specifically the Blesbok Spruit catchment forms part of the Vaal River Barrage secondary catchment. The Blesbok Spruit catchment contains the Gauteng Province's major wetland system which has an area of approximately 1858 km^2, extends 21 km along the Blesbok Spruit, is known to support 250 species of birds and is a habitat to many species of fauna and flora which form an integral part of the ecosystem. The Blesbok Spruit wetland has been recognised as a wetland of international importance and consequently been given RAMSAR status since 1986, however it has been placed on the Montreaux Record due to extensive pollution (Haskins 1998; Dini 1998; Schoeman and Steyn 2000; DWS 2006).

Fig. 5.6 Mooi River catchment with major dams, rivers and urban landmark

Lastly, the Kromdraai catchment, herewith referred to as the Mooi River catchment, can be divided into three quaternary catchments, namely the Mooi River, Loop Spruit and the Wonderfontein Spruit (Mooi River Loop). The upper reaches of the catchment are situated on the Far West Rand area of Gauteng Province and the lower reaches of the catchment are situated in North-West Province. The catchment is characterised by various dams, namely the Donaldson, Klipdrift, Boskop and Potchefstroom Dams as illustrated in Fig. 5.6.

The tributaries of the Mooi River catchment receive pollutants from a wide variety of sources, such as mine residue deposits from several old and abandoned mines and from numerous active gold mines. This area is underlain by dolomite and the withdrawal of water from the gold mines is taking place in three of these dolomite compartments. Furthermore, the catchment includes a number of magisterial districts such as Potchefstroom, Westonaria, Oberholzer, Fochville and Carletonville. The catchment is also characterised by growing developments and informal developments, including Kagiso, Mohlakeng, Toekomsrus, Rietvallei and Bekkersdal. All of these may contribute to future pollution in the Mooi River catchment (DWS 2003a, 2004b).

The Upper Vaal WMA thus covers a relatively large area and is very important to the South African economy and for future development. The three main secondary catchments are all characterised by different types of development, and future growth in these regions is inevitable.

5.3 Geology and Soils

The dominant geology of the region is made up of Karoo sediments, Transvaal dolomites, Witwatersrand quartzites, Ventersdorp lava, and other minor geological types (DWS 2004b). The geology of the catchment area can be described as homogeneous, consisting of fine sedimentary rocks belonging to the Karoo Super Group. The Vaal Dam drainage area (80%) is underlain by rocks that are predominantly from the Karoo Super Group. The geological formations of the Karoo Super Group include the Ecca, Beaufort and Stormberg Groups. When eroded, this super group releases mainly illitic clay minerals.

The distribution of the geological formations in this region is closely related to the topography of the area. The highest-lying ground belongs to the Stormberg Group (Chutter 1970; Basson 1978; Eriksson 2005).

The Ecca Group, which occurs in the northern half of the catchment area, is the oldest Karoo deposit found in the area and consists of shale, sandstone, pyroclasts and coal (Basson 1978). Regions situated north of the Vaal River are characterised by metamorphic and igneous rocks (compact sedimentary strata and compact sedimentary intrusive and extrusive rocks). However, extensive Transvaal Super Group outcrops, which consist of dolomite, chert and subordinate limestone, occur in the central areas of the catchment, mainly in the Mooi tributary (Pitman and Lauchli 2002; DWS 2004b).

A characteristic of the Karoo Super Group is the occurrence of numerous intrusive dykes and sills of igneous rock, known as Karoo dolerite. The dolerite is more resistant to erosion than the sedimentary rocks and, as a result, almost all the rapids and cascades in the streams and the rivers within the Vaal River catchment area cut through the doleritic dykes or where the sills are exposed in their beds (Chutter 1970; Eriksson 2005).

The younger Beaufort Group deposits occur predominantly in the southern part of the catchment area. These deposits consist mainly of shale, mudstone and sandstone (Basson 1978). The youngest deposits of the Stormberg Group occur in the extreme south, in a small region consisting of sandstone, shale and mudstone. Small intrusions of other formations, which have led to the formation of solzenetic soils, occur along the southernmost border (Basson 1978; DWS 2004b).

Under natural conditions, the dolerites in this catchment area lead to low total dissolved solid (TDS) values in the water. The Ecca sediments make for elevated

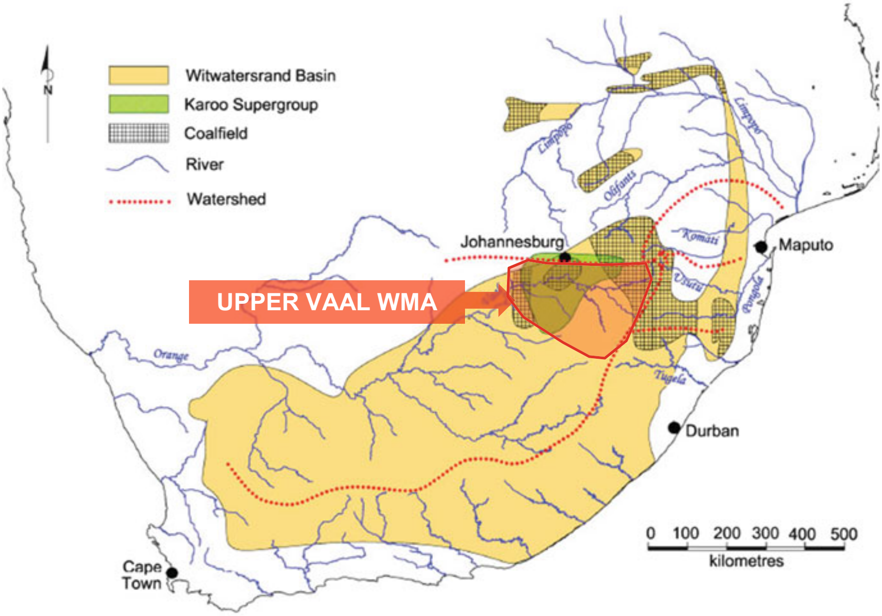


Fig. 5.7 Distribution of coalfields in the Witwatersrand Basin and the Karoo Supergroup (McCarthy 2011)

levels of natural salinity, and therefore, relatively higher sodium and chloride levels, which can be attributed to the nature of the formation. The eastern and north-eastern portions of the WMA are characterised by high alkalinity levels. The Beaufort sediments are similar to the Ecca sediments. However, the former have lower salinity levels under natural conditions (Basson 1978; DWS 2004b).

The minerals predominating in the region include gold (in the Witwatersrand basin), uranium, base metals, semi-precious stones and industrial minerals. Gold, uranium and coal are of economic importance and are widely distributed throughout the WMA, as indicated in Fig. 5.7. However, these mining operations impact upon the water quality and cautious consideration should be given to future mining developments (DWS 2004b).

The soils located in the south-eastern parts of the Vaal Dam catchment area are described as having more of a sandy nature with their horizons thicker than those in the northern area (Chutter 1970). When the Karoo Super Group rocks are weathered, they release mainly illitic clay minerals (Birch 1983). Sediments that have accumulated in the Vaal Dam are described by Birch (1983) as being enriched in kaolinite and in the smectite group of clay minerals, which in turn affect the colour of the water (turbidity) of the Vaal Dam.

Soil depths in the Upper Vaal area upstream of the Vaal Barrage in the vicinity of Vereeniging are described as moderate to deep (500–1200 mm). These depths are related to the undulating relief in that soils are generally deeper in the valleys than on the hill crests. The three main soil types distributed across the catchment are:

- ***Sandy Loam:*** in the upper reaches of the Vaal and Wilge catchments, as well as to the north of the Vaal River, along its central reaches;
- ***Clayey Loam:*** in the Klip and Suikerbosrant sub-catchments, as well as to the south of the Vaal River, along its central reaches;
- ***Clayey Soil:*** in the middle and lower catchments of the Wilge and Vaal River catchments, upstream of the Vaal Dam, as well as to the west of the Vaal (Fey and Guy 1993; DWS 2004b).

The soils in the Upper Vaal WMA are thus clayey and the underlying geological formation belongs to the Karoo Super Group. The geology and soils of the study area impact upon the quality of the water in the WMA by raising the TDS levels and thus developing a high sediment load in the water column.

5.4 Topography

The Drakensberg mountain range is described as the major topographical feature of the Vaal Dam catchment area and forms the south-eastern, as well as most of the eastern boundary. The Wilge tributary rises on the inland plateau at an elevation of approximately 3200 m above sea level, and the catchment area slopes down to an elevation of 1450 m at the Vaal Dam (DWS 1997; Kneidinger 2007).

The Highveld is characterised by a gently undulating to flat topography with shallow, open valleys that reflect the Post-African 1 erosion surface (Partridge and Maud 1987). The longitudinal profiles of the rivers in the region are gentle and stepped at doleritic sills, with many having well-developed meander belts often approximately related to the North-South and East-West rock jointing (Scheidegger 1985). The topography consists of various dry valleys and gravel terraces, which reflect the ancient drainage lines. The region is also marked by a low hydrological variability (Sohnge et al. 1937; DWS 2003a).

The topography of the Vaal Dam catchment area gently slopes from approximately 1800 m in the east to 1450 m in the vicinity of the Vaal Barrage in the west. Steep areas occur on the south-eastern border of the Orange River and in the headwaters of the Wilge tributary, as indicated in Fig. 5.8. The area located between the confluence of the Vaal and the Rietspruit rivers is relatively flat, with the maximum elevation being about 2200 m above sea level in the upper reaches of the Vals River. Water from the Vaal Dam flows across the Middle Vaal, Lower Vaal and Lower Orange WMAs before reaching the Atlantic Ocean, close to the town of Alexander Bay in the western corner of South Africa (DWS 2004b).

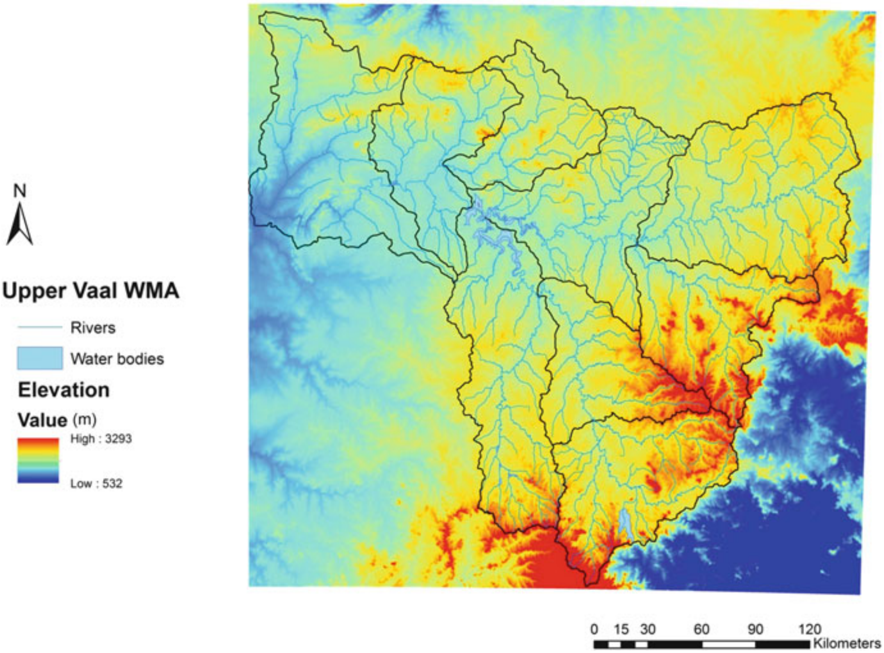


Fig. 5.8 Topography of the Upper Vaal WMA

5.5 Hydrology

The largest proportion (46%) of the surface water of the Upper Vaal area, located upstream of the Vaal Barrage, is contributed by the Vaal River upstream of the Vaal Dam, as well as by its main tributary, the Klip River. The Wilge River and the Liebenbergsvlei River contribute 36% to the WMA's surface water, with the remaining 18% being sourced from tributaries located downstream of the Vaal Dam. The amount of runoff has increased in the area due to impermeable surfaces in the expanding urbanised areas. The natural mean annual runoff of the area is approximately 2423 million m^3. No significant afforestation occurs in the Upper Vaal WMA. Numerous farms have dams which have a negative effect on the water entering the Vaal Dam (DWS 2004b).

The Wilge, Klip, Liebenbergsvlei, and Vaal Rivers supply the Vaal Dam with water. The magnitude of the natural inflow into the Vaal Dam is approximately 1950 million m^3 per annum. However, the Grootdraai and Sterkfontein Dams reduce this inflow to approximately 1400 million m^3 per annum (DWS 1997, 2003b).

The growing demand in the Vaal River System Supply Area has resulted in the inability of the water resources of the Vaal Dam catchment area to meet the full demand for water. In order to address this problem, various inter-basin water transfer schemes have been implemented and are continually being developed to transport water from areas with excess water resources to the Vaal Dam catchment area (DWS 1997). Water is thus imported from the Upper Orange (Lesotho), Thukela, Usutu and Komati catchments, as well as exported to the Limpopo/ Crocodile and Olifants catchment areas (Braune and Rogers 1987).

The geohydrology of the WMA is diversified. An important feature in the Upper Vaal area is the large dolomitic aquifer—which extends across the north-western section of the region. Most of the water in the Mooi River, which is known for its strong basal flow, has its source in this aquifer as springflow. Large volumes of groundwater are abstracted through pumping for urban use and for irrigation. Increases in groundwater abstraction could result in a decline in surface flow as a result of the direct connections between the dolomitic aquifers and the surface streams. The withdrawal of water from these dolomitic compartments could also result in the formation of sinkholes, as evidenced in the north-western section of the WMA where gold-bearing conglomerates underlie the dolomite. A temporary increase in surface flow occurs while the water table is being lowered. Once pumping by the mines has ceased and the dolomitic compartments are allowed to fill up again, the result may be a reduction in stream flow for several years (DWS 2004a, b).

The area is characterised by underlying fractured rock aquifers, which are used for rural domestic water supplies, as well as for stock watering. Even though groundwater plays an important role in some areas, only 3% of the total water requirements in this WMA are supplied by groundwater. The groundwater in the WMA is generally of a high standard, in spite of the fact that chemical reactions take place when the groundwater filters down into various mine caverns, in which case, the water quality often deteriorates and could cause considerable pollution when the water decants or seeps out from such caverns. The West Rand area of Johannesburg located close to Krugersdorp and Randfontein, is a textbook example of the decanting of heavily polluted groundwater or AMD and may consequently degrade the WMA further due to the inflow predominantly into the Mooi River catchment (DWS 2004a, b).

5.6 Climate

As defined by Schulze (1965), the Upper Vaal WMA is located in the Sub-humid Highveld Climatic Zone. The mean annual temperature ranges between 16 °C in the west and 12 °C in the east, with an average of approximately 15 °C for the catchment area as a whole, located upstream of the Vaal Barrage in the vicinity of Vereeniging. Maximum temperatures are experienced in January and minimum temperatures usually in July (Pitman and Lauchli 2002).

The WMA is characterised by seasonal rainfall, with most rain occurring in the summer period from October to April. The peak rainfall months are December and January. The mean annual rainfall decreases from 1000 mm in the south-east to 700 mm in the west, with an approximate average of 740 mm. The mean annual rainfall of the area is marked by a fairly uniform decrease in rainfall from the eastern escarpment regions, across the central plateau area, westwards (DWS 2004b).

Rain occurs in the form of convective thunderstorms and may sometimes be accompanied by hail. Winters are characterised by frost and the possibility of occasional light snowfalls on high-lying areas in the catchment area (Basson 1978; Pitman and Lauchli 2002; DWS 2004b).

5.7 Ecology

The Upper Vaal Area, situated upstream of the Vaal Barrage in the vicinity of Vereeniging, includes ecologically-sensitive areas. The identified areas include wetlands in the catchment of Suikerbosrant River, Klip River, as well as in the Wakkerstroom area of the WMA. The Blesbok Spruit wetland, which occurs in the Suikerbosrant catchment area, has been listed as a wetland of international importance, as defined in the RAMSAR Convention but has consequently been placed on the Montreaux Record due to persistent pollution especially from the Grootvlei mining operations into the wetland. The Golden Gate National Park is situated in the southern section of the WMA, while other conservation areas are scattered throughout the WMA (DWS 2004b).

The Upper Vaal WMA is rich in bird species and also accommodates a wide variety of species (Rand Water 2006a), but Botha's lark (*Spizocorys fringillaris*), which inhabits heavily-grazed grasslands, is the only strictly endemic bird species in this region. Seven other near-endemic bird species also occur in the region, namely:

- the blue korhaan (*Eupodotis caerulescens*);
- the buff-streaked chat (*Oenanthe bifasciatai*);
- the melodious lark (*Mirafra cheniana*);
- Rudd's lark (*Heteromirafra ruddi*);
- the southern white-bellied korhaan (*Eupodotis cafra*);
- the white-winged fluff tail (*Sarothrura ayresii*); and
- the yellow-breasted pipit (*Hemimacronyx chloris*) (Bowie and Frank 2001).

The Upper Vaal WMA also provides a habitat for various animals. However, the Orange mouse (*Mus orangiae*) is restricted to the grasslands, while the rough-haired golden mole (*Chrysospalax villosa*) is the only near-endemic species that occurs in the region. Herds of large mammals, such as the Black wildebeest (*Connochaetes gnou*) and White rhino (*Ceratotherium simum*), previously roamed the region but were exterminated by early settlers (Bowie and Frank 2001). Various other large mammal species that are found in the region include the following:

- the aardwolf (*Proteles cristatus*);
- the African civet (*Civettictis civetta*);
- the brown hyena (*Hyaena brunnea*);
- the honey badger (*Mellivora capensis*);

- the leopard (*Panthera pardus*);
- the mountain zebra (*Equus zebra hartmannae*);
- the oribi (*Ourebia ourebi*);
- the pangolin (*Manis temminckii*); and
- the sable antelope (*Hippotragus niger*) (Bowie and Frank 2001).

The Upper Vaal WMA is also characterised by several fish species, as indicated in Table 5.2 (Rand Water 2006b). Approximately 29 amphibian species occur in the catchment area. However, none are endemic. As a result of the cool climate, there

Table 5.2 Selected fish species found in the Upper Vaal WMA (Rand Water 2006b)

Common name	Scientific name	Indigenous or exotic	Habitat
Banded tilapia	*Tilapia sparrmanii*	Indigenous	In slow-flowing rivers with submerged or emergent vegetation
Chubby-headed barb	*Barbus anoplus*	Indigenous	Amongst the vegetation and tree roots on the marshy margins of rivers, on logs in rivers and at the Vaal Barrage
Goldie barb	*Barbus pallidus*	Indigenous	In the marginal vegetation in rivers and pools
Large-mouthed yellowfish	*Barbus kimberleyensis*	Indigenous	In rivers and at the Vaal Barrage where there are strong currents
Mud mullet or Moggel	*Labeo umbratus*	Indigenous	At the Vaal Barrage and in slow-flowing rivers
Orange river mudfish	*Labeo capensis*	Indigenous	In flowing rivers and at the Vaal Barrage
Rock catfish	*Austroglanis scaleteri*	Indigenous	In the rapids of flowing rivers
Sharp-toothed catfish	*Clarias gariepinus*	Indigenous	In rivers and at the Vaal Barrage
Small-mouthed yellowfish	*Barbus aneneus*	Indigenous	In rivers and at the Vaal Barrage; on the sandy bed or on rocks
Southern mouthed brooder	*Pseudocrenilabrus philander*	Indigenous	In flowing rivers and at the Vaal Barrage, usually with vegetation
Straight-finned barb	*Barbus paludinosus*	Indigenous	Along rivers, in their well-vegetated areas (marshes and wetlands)
Common carp	*Cyprinus carpio*	Exotic	At the Vaal Barrage
Large-mouthed bass	*Micropterus salmoides*	Exotic	In clear standing water where there is a vegetational cover
Mosquito fish	*Gambusia affinis*	Exotic	In standing water where there is a vegetational cover

are only a few reptile species. The most common reptile species that occur in the catchment include the following:

- the African rock python (*Python sebae*);
- Breyer's whiptail (*Tetrodactylus breyeri*);
- the Drakensberg rock gecko (*Afroendura niravia*);
- the giant girdled lizard (*Cordylus giganteus*);
- the giant spiny-tailed lizard (*Cordylus giganteus*);
- the Nile crocodile (*Crocodylus niloticus*);
- the veld monitor (*Varanus exanthematicus albigularis*); and
- the water monitor (*Varanus niloticus*) (Bowie and Frank 2001).

The Vaal Dam catchment is characterised by the predominant veld type, 'pure grassveld', also known as 'grasslands', which previously covered the whole catchment area (Acocks 1988). However, most of the catchment area is now under cultivation, including wheat cultivation in the colder southern parts of the Wilge River catchment area, and maize cultivation in the remaining catchment area. The north-eastern parts of the catchment area have been subjected to afforestation (Basson 1978). Temperate and transitional forest and scrub occur in the Upper Wilge catchment and along the escarpment, which receives a higher rainfall, from approximately 700 to 1000 mm. False grassveld predominates to the north of the Vaal River, but also especially in the Mooi River catchment area (Pitman and Lauchli 2002; DWS 2004b). Table 5.3 shows the selected vegetational types that occur in the Upper Vaal WMA.

The Grassland Biome is characterised by an extremely large biodiversity, second only to the Fynbos Biome. The rare plants of the Grassland Biome are especially prevalent close to the escarpment and are often endangered. These rare species consist of endemic geophytes or dicotyledonous herbaceous plants (Meadows 1985, 2005; Low and Robelo 1996).

The grasslands are dominated by a single layer of grass, the density of which is closely related to the intensity of grazing, as well as to the amount of rainfall. Trees are largely absent. However, they do occur in some localised habitats. Geophytes or bulbs are abundant. Two types of grass plants have been identified: firstly, the sweet grasses, which have a low fibre content and retain nutrients in their blades during the winter season, and secondly, the sour grassveld species, which are short and dense, have a high fibre content and store nutrients in their roots during the winter. As a result of the retention of nutrients in its roots, the grass is largely unpalatable to stock. Grazing, frost and fire work in concert to prevent trees from establishing themselves and to maintain the dominance of grass (White 1983; Bredenkamp et al. 1996).

Table 5.3 Vegetational types of the Upper Vaal WMA (modified from Bredenkamp et al. 1996)

Common name	Scientific name
Bankrupt bush	*Stoebe vulgaris*
Bitter Karoo bush	*Pentzia globose*
Broom needle grass	*Triraphis andropogonoides*
Brown saffron bush	*Sutera atropurpurea, Deverra burchellii, Helichrysum rugulosum, H. caespititium, H. dregeanum, Crabbea acaulis, Hermannia depressa* and *Rhynchosia totta*
Dwarf buffalo thorn	*Ziziphus zeyheriana*
Elephant's root	*Elephantorrhiza elephantine*
Rattle bush	*Blepharis integrifolia*
Red grass	*Themeda triandra*
Sawtooth love grass	*Eragrostis superb*
Small Bietou grass	*Osteospermum scariosum* and *Walafrida densiflora*
Tassle bristle grass	*Aristida congesta, Couchgrass Cynodon dactylon, Eragrostis obtusa, Aristida canescens, Microchloa caffra* and *Tragus berteronianus*
Velvet signal grass	*Brachiaria serrata, Elionurus muticus, Heteropogon contortus, Cymbopogon plurinodis* and *Setaria spacelata*
Weeping love grass	*Eragrostis curvula*
Wild petunia	*lpomoea obscura*

5.8 Land Cover and Land Use

The Upper Vaal WMA is densely populated, being characterised by sprawling urban and industrial areas in the western and northern areas. The present water-consumption sectors in the WMA include the Ecological Reserve (environmental and in-stream requirements), domestic consumers (urban and rural), bulk water consumers (the mines and coal-fired thermal power stations), agriculture (cultivation, livestock and game farms), afforestation, alien vegetation and consumers involved in water transfers (Pitman and Lauchli 2002).

Water is described by Hohls et al. (2002) as a solvent, as well as a transport medium for particulates. As a result, water tends to become polluted through natural processes and also through human-induced processes and waste. The focus at this stage is on those natural processes that could play a role in impacting on the quality of the water in the WMA. These natural processes could include the following:

- The *topography* is considered to be one of the factors as it influences the climatic conditions and also surface runoff.
- The *climate* of the region also plays a role in terms of the amount of rainfall and its distribution in space and time.

- The *geology* could affect the water quality as it determines the water chemistry and also the properties of the riverbed.
- *Soils* determine the overall natural nutrients and salt loads.
- Lastly, *vegetation* plays a role in that it influences the stream flow, as well as the total surface runoff from the banks of the dams and the rivers (Avenant-Oldewage and Eddy 2003).

The natural landscape has been transformed and manipulated physically and chemically in order to meet society's needs. The changes of land cover and land use have consequently been accompanied by various impacts on a specific region's hydrological responses and ultimately its water resources (Warburton et al. 2012; Attua et al. 2014; Pillay et al. 2014). As stated by Warburton et al. (2012) for a catchment or region to improve upon its water resource planning and management, an understanding is required of the interactions between hydrological responses and land use. The increasing demands from society as well as economic pressures will be accompanied with further land cover changes within regions and contribute to future water availability and possibly water quality problems in the near future.

Approximately 40% of South Africa's agricultural production is based on agricultural activities in the wider Vaal Dam catchment area, with intensive cultivation, mixed farming and stock farming dominating. The main irrigated crops that are cultivated here are low-value crops including maize, wheat, vegetables, flowers, pasture crops and grass (Braune and Rogers 1987; Pitman and Lauchli 2002; DWS 2004b). The application of fertilisers and pesticides, and feedlots in the case of livestock rearing, could negatively impact upon the water body, with increased salinity, turbidity, nutrient pollution and also pesticide pollution being some of the consequences (DWS 2002, 2004b; Pitman and Lauchli 2002; Avenant-Oldewage and Eddy 2003).

Owing to the lack of sufficient water in the Pretoria–Witwatersrand–Vereeniging (PWV) complex, the Vaal Dam was primarily constructed for the storage of water. However, the increasing demand for open air facilities has seen the Vaal Dam and its riparian areas being used for recreational activities. With the exception of Deneysville and Oranjeville, the immediate area surrounding the dam (500 m from the water's edge), for instance, is zoned for tourist or recreational activities, nature reserves or open spaces. Also associated with recreation are several residential suburbs/complexes and resorts which have been opened up to development in or close to the riparian zone. Recreational activities such as fishing, swimming, canoeing, water-skiing, sailing, and powerboat racing, and non-consumptive activities such as bird and wildlife watching, camping and picnicking, are practised mainly in the region between the Vaal Dam and the Bloemhof Dam.

The impacts associated with such recreational activities could include oil and fuel spills, litter, sewage, bank erosion, the re-suspension of sediments through boating activities, the modification of the riparian zone and the introduction of alien plant species (Braune and Rogers 1987).

Approximately 60% of the country's mines and industries are located in the Vaal River catchment area. Braune and Rogers (1987) stated that these human activities have had an impact on the quality of the water in the Vaal Dam. The products of the mining industry include coal, precious metals, base metals, semi-precious stones and industrial minerals (DWS 2004b). In the case of gold mining, the majority of these mines are located in the vicinity of the Vaal River Barrage, Bloemhof Dam, and the Vaal Dam catchment area. Hence, the effluent produced by the mines located in the northern and western parts of the WMA affects the quality of the water (Crafford 2000).

Gold mining operations contribute to water pollution through acid water drainage, the runoff from old mine dumps and washing processes, and explosives used in the mining operations. As a result, the pH values of the water in this area are reduced, the salt content is relatively high and there are certain solids such as iron particulates that have totally dissolved in the water. Yet another pollutant in the water body is sulphuric acid (Braune and Rogers 1987; Pieterse 2000).

Coal mining is practised mainly in the northern and eastern parts of South Africa. Coal mining in the Vaal River catchment is limited to the Vaal Dam and the Vaal River Barrage catchments and is based on open-cast and also underground mining operations. The impacts of the coal mining operations on the quality of the water in the Vaal Dam catchment area might include increased acidity, increased concentrations of sulphates and totally dissolved solids, and a lowered oxygen content, all contributing to the overall degradation of the aquatic ecosystem (Pieterse 2000; DWS 2004b).

In terms of industrial development, the DWS is concerned about the increase in sources of diffuse pollution. The major wet industrial operations, including power generation, textile manufacturing, paper and pulp production, iron and steel production, synthetic fuel processing and meat production (abattoirs) are considered to be the main industries in South Africa (Avenant-Oldewage and Eddy 2003). Power generation and fuel production, are the dominant industries in the Vaal Dam catchment area. The Sasol I fuel plants, Mittal Steel (previously known as ISCOR), and Sappi and Sasol Synthetic Fuels at Secunda, are all located in the Vaal Dam catchment area (DWS 1993).

Major water-related problems are caused through atmospheric pollution, oil spills, effluent pollution (phosphorus, nitrates, ammonia, sodium, fluorides and non-biodegradable organic compounds), as well as the release of highly alkaline washing waste water (DWS 1993).

Industries generally cooperate in order to prevent pollution. However, the assimilative capacity of the Vaal River exceeds the stipulated guidelines in terms of specific water quality parameters. The DWS has highlighted the necessity of incorporating stricter point-specific effluent standards (DWS 1993).

Together with the economic activities performed in the urban areas, the mines, as well as the industries, located in the northern part of the WMA, together with similar developments in the southern parts of the Crocodile West and Marico WMA, contribute 45% to the country's GDP. It is estimated that approximately 20% of this originates in the Upper Vaal WMA, which is the second-largest contributor of all the WMAs to the country's national wealth.

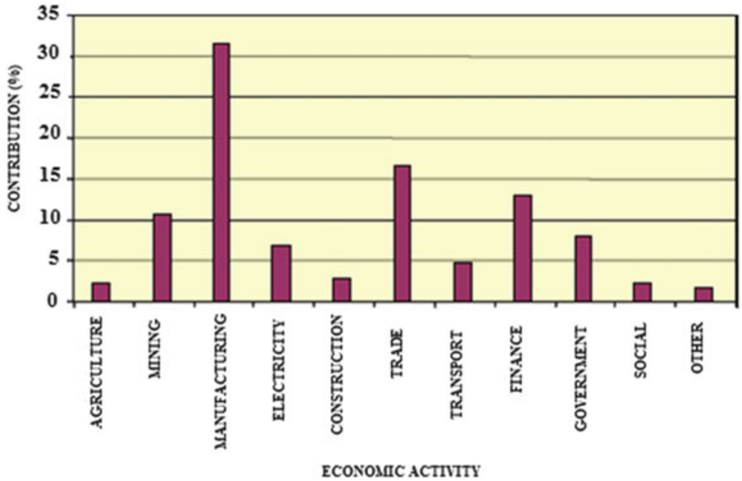


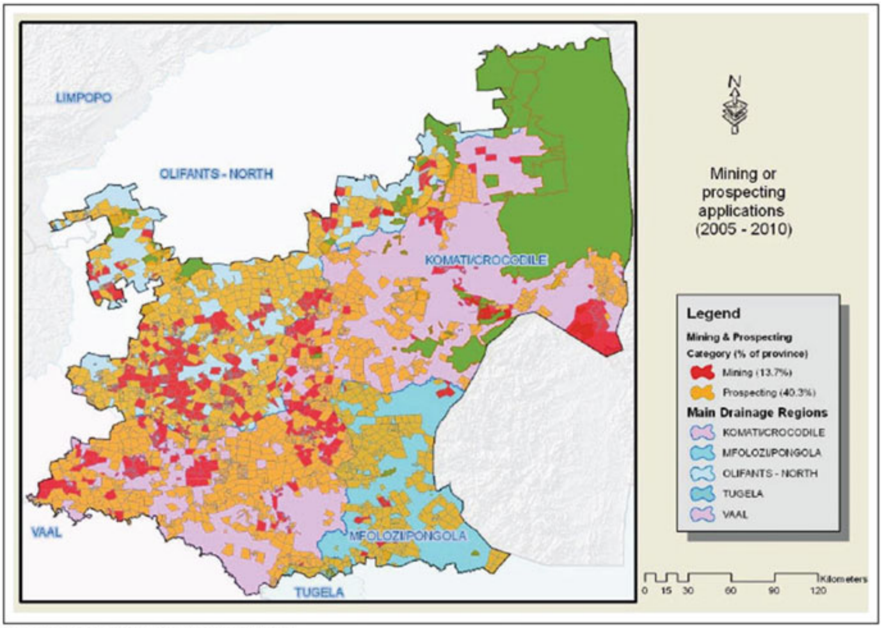
Fig. 5.9 Sectoral contribution to the GGP of the Upper Vaal WMA (DWS 2004b)

Figure 5.9 shows that the manufacturing sector contributes the most (approximately 30%) to the Upper Vaal WMA's Gross Geographical Product (GGP). This is followed by the trade sector, contributing just over 15%, and both finance and mining the respective contributions of which are slightly higher than 10%. Even though the WMA is dominated by agricultural activities, this sector only contributes two percent (2%) to the GGP. However, it is a significant sector in terms of providing livelihoods to the rural population in the WMA and of providing important linkages to other sectors (DWS 2004b).

Economic activities on the agricultural front in the rest of the WMA include mainly livestock and dryland farming. With the high level of urbanisation and other economic activities in the WMA, the water resources are highly developed and regulated and it has been stated that the potential for further development is only marginal. The projections in terms of population and economic growth remain positive for the urban and industrial areas of the WMA.

This growth will be largely due to the urban and industrial areas in the Johannesburg–Vereeniging–Vanderbijlpark complex and the new gold mining developments, which will be replacing the older worked-out mines. Large coal reserves are present in the north-eastern area of the WMA. Figure 5.10 shows that there are numerous prospective mining applications in the Upper Vaal WMA, which may have numerous impacts on both the quantity and the quality of the water. The DWS expects these coal reserves to be exploited in the medium to long term. A prospective mining application has recently been submitted by Mintails Mining Company in the Krugersdorp–Randfontein area for the re-mining of gold mine dumps and other areas within that region (McCarthy 2011).

In conclusion, in terms of its land use, the Upper Vaal WMA is characterised by sprawling urban and industrial areas in its northern and western parts, as well as by extensive coal and gold-mining activities which are scattered across the WMA.



Source: Dr J Pretorius, Foundation for Sustainable Environment.

Fig. 5.10 The current mining areas, as well as prospective mining areas, in the upper catchments of the Vaal, Olifants, Komati and Mfolozi-Pongola Rivers in Mpumalanga Province (McCarthy 2011)

These activities generate return flow volumes of water in the form of treated effluent from urban and industrial areas and of mine waste water that are discharged into the river system. The discharges from the land use activities have had significant impacts on the quality of the water in the Vaal River throughout its course, namely in its upper, middle and lower courses (DWS 2011).

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Chapter 6
Primary Water Quality Challenges for South Africa and the Upper Vaal WMA

The quality of the water in South Africa and the Upper Vaal WMA is affected by both natural processes such as seasonal trends, the underlying geology, weather and climate, as well as by human activities. The most significant water quality issues include salinity, eutrophication, microbial pollution, sedimentation and recently added acidification as a result of the century-long legacy of unregulated gold mining and high density populations living in close daily contact with dust and sediment arising from mine tailings. The significant global water quality issues, as identified by UNEP GEMS, should also be considered as they relate directly to the present pressures on the country's water quality. The pollution of these freshwater resources has been accompanied by a decline in water quality, bringing with it public health issues, but also a reduction in the economic value of the available water. With the continued population growth, investments will have to be made in both developed and developing countries in terms of the improvement and maintenance of water treatment and supply infrastructures, as well as of sanitation facilities. Focus is placed on the main water quality challenges within South Africa and the Upper Vaal WMA and their influence on both environmental and human health.

6.1 Introduction

The UNEP has stated that numerous water bodies providing drinking water to thousands of inhabitants in Africa are showing unacceptable levels of potentially toxic substances that have been derived from local industries and domestic waste water. African towns and cities have better water supplies and sanitation services than the rural areas and two-thirds of the African population live in rural areas. Therefore microbial pollution, as well as eutrophication, are major concerns. The quality of the water in South Africa as well as the Upper Vaal WMA is affected by both natural processes such as seasonal trends, the underlying geology, weather

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_6

and climate, as well as by human activities. Domestic sector consumption, water usage by agriculture and industry, and water made available through environmental engineering, are examples of the last-mentioned aspect (Jones and van der Walt 2004; Abbaspour 2011).

The main culprits[1] in causing pressure to bear on the country's water resources are:

- industry;
- urban development;
- stormwater;
- informal housing developments;
- sewage treatment works and sewer reticulation systems;
- agriculture;
- mines: excess mine water; tailings, residue dumps, including quarries; and
- general waste disposal sites (DEAT 2003).

The largest threat to the country's as well as the Upper Vaal WMA's water supply is not the lack of storage facilities but rather the contamination through pollution of the available water resources which is also affected by the main contaminants of freshwater. The DWS defines water quality as the 'fitness of use it possesses' and describes its physical, chemical, biological and aesthetic properties (DWS 1996; CSIR 2010). The DWS has developed several guidelines based specifically on how the consumer should use water, as well as its required quality standards.

The DWS (1996) determines water quality by taking the following criteria into account:

- Water quality problems that are associated with a particular type of water usage;
- The effects of poor water quality;
- The common norms to measure the quality of the water that is to be used;
- Those components of water quality that are generally considered to be cause for concern;
- Lastly, those particular attributes/properties which could have an effect on the quality of the water to be used (DWS 1996, 1998).

The four significant water quality issues, as recorded by Roux et al. (2010), are salinity, eutrophication, microbial pollution and sedimentation. Recently, however acidification has been added to this list as a result of the century-long legacy of unregulated gold mining and high density populations living in close daily contact with dust and sediment arising from mine tailings. The significant global water quality issues, as identified by UNEP GEMS, should also be considered as they relate directly to the present pressures on the country's water quality. A discussion on the significant water quality issues in South Africa now follows.

[1] But not limited to these.

6.2 Sewage or Microbial Pollution

Even though we know that discharges of untreated sewage could cause illness and death, contaminated water is still routinely discharged from various pollution sources such as homes, hospitals and industrial facilities. A small drop of faecal matter contains millions of micro-organisms of numerous types. Some of these are pathogenic by nature (Dorfman 2004; UNEP GEMS Water 2009; Omari and Yeboah-Manu 2012). Microbial pollution is caused by pathogenic organisms and impacts upon both humans and the environment.

The lack of sanitation services is one of the major causes of microbial pollution. The World Health Organisation estimated in 2008 that approximately 2.6 billion people lacked improved sanitation facilities. Most of these affected populations are in Eastern Asia, followed by Southern Asia and Sub-Saharan-Africa. The lack of sanitation facilities affects poor communities in both urban and rural areas—mainly where resources for the investment in the collection and treatment infrastructures are lacking. The wealthiest communities of the world can also be affected by outbreaks of microbial pollution since the maintenance of existing systems can be challenging (UNEP GEMS Water 2009; Omari and Yeboah-Manu 2012).

The improper disposal of sewage poses a risk in developed and developing nations across the world. Sewage is produced by domestic, as well as industrial activities as either black or grey water. Black water sewage includes faeces, urine, paper, condoms and any other material that people find convenient to flush down toilets. Grey water on the other hand consists of the outflow from wash basins, kitchens, baths and sinks and includes food remains, oil, detergents, as well as dirt. Sewage can be discharged intentionally to waterways through pipes or open defecation methods, or unintentionally through runoff during rainfall events (UNEP GEMS Water 2009; Omari and Yeboah-Manu 2012).

People are exposed to these organic pathogens when they use the waterways for drinking, sanitation or recreational use, and can become ill by ingesting contaminated water, by preparing food with it, or even by merely inhaling the contaminated droplets. Thus, in terms of microbial pollution, the largest concern to human and animal populations after having been exposed to contaminated water is the risk of illness or even premature death (UNEP GEMS Water 2009; Omari and Yeboah-Manu 2012).

The discharge of untreated sewage into waterways poses major health risks to human health, could destroy aquatic ecosystems and could threaten human livelihoods. Associated human illnesses include amongst others meningitis, typhoid fever, salmonella infections, cholera, septicaemia, and diarrhoea. Edible filter-feeding shellfish such as clams, mussels, oysters and scallops which eat plankton, microscopic plants and animals by filtering them from the water can re-infect humans with concentrations of viruses that range between 100 and 900 times greater than those for the surrounding water (Dorfman 2004; Omari and Yeboah-Manu 2012).

At greatest risk are communities downstream of the pollution source area and people providing for or indulging in recreation in the infected waters. Coliforms are used as the indicator organisms for detecting the presence of faecal contaminants in the water, and the size of the population of the area correlates positively with the levels of *Faecal coliform* bacteria in the affected rivers or water bodies.

Microbial pollution will not disappear overnight as the large increase in human populations across the world is accompanied by increased effluent discharges and increased volumes of waste water. Urbanisation is also accompanied by an increase in water consumption and consequently increased sewage output as people switch from pit latrines to flush toilets (UNEP GEMS Water 2009; Omari and Yeboah-Manu 2012).

Microbial pollution is increasing in South Africa as well as within the Upper Vaal WMA owing to a proliferation in human settlements, inadequate and ineffective sanitation and waste disposal practices, increased runoff from the impervious surfaces of urban areas, large volumes of stormwater wash-off, and sewage spills (CSIR 2010; de Lange et al. 2012). To compound the problem, many of the municipal waste water treatment works cannot cope with the larger loads.

The Middle Vaal WMA has shown a significant overall increase in microbial pollution from 2003 to 2006 (van der Merwe-Botha 2009; Roux et al. 2010). The main health risk areas in terms of surface water that have been identified on account of faecal pollution are the Elands and Klein Letaba Rivers in Mpumalanga, the towns of Kokstad, Newcastle, and Matsulu, and the Nsikazi River in KwaZulu-Natal, the towns of Mahikeng and Makopanstad in North-West province, the Buffels River in Eastern Cape, Phuthaditjhaba in Free State, Polokwane and Lebowakgomo in Limpopo, (and Tshwane) as well as the Olifants, Elands and Apies Rivers in Gauteng—to name but a few (Kuhn et al. 2000; CSIR 2010).

The pollution of these freshwater resources has been accompanied by a decline in water quality, bringing with it public health issues, but also a reduction in the economic value of the available water (Roux et al. 2010; Kinge and Mbewe 2012). With the continued population growth across the world, investments will have to be made in both developed and developing countries in terms of the improvement and maintenance of water treatment and supply infrastructures, as well as of sanitation facilities.

6.3 Eutrophication

Eutrophication can be described as a natural process where surface waters are enriched with plant nutrients. While this process occurs naturally, it is normally associated with the excessive nutrient enrichment of waters which promotes excessive growth in algae and in other aquatic plants. It typically results in problems associated with macrophytic, algal and cyonabacterial growth. Natural eutrophication is caused through the influx of nutrients from natural sources such as rocks, soils and other natural features in the catchment area. The eutrophication process is thus a natural aging process taking place in water bodies. It is irreversible and uncontrollable. However, this process is accelerated through inputs of anthropogenic-sourced nutrients, particularly through nitrogen and phosphate enrichment (NO_2, NO_3, NH_4 and PO_4) (DWS 2002; Glibert et al. 2005; Oberholster et al. 2009; van Ginkel 2011). The process is characterised by a change from one trophic state to a higher one through the addition of nutrients.

Eutrophication is caused by the following trends:

- Indirect causes:
  - Accelerated population growth and the densification of urban settlements;
  - Economic growth associated with alterations to the watershed or catchment area, as in the case of the construction of dams for water storage to meet the needs of the growing population.
- Direct causes:
  - Increased energy and fertiliser consumption to meet the needs of the growing population;
  - Increased discharges from waste water treatment works;
  - Intensive farming practices associated with increased nutrient-polluted return flows;
  - Poor agricultural practices as in the cultivation of riparian zones on the margins of water bodies; and
  - Land use conversions.
- Other causes:
  - Overfishing; and
  - Climate change (DWS 2002; Glibert et al. 2005; Oberholster et al. 2009; van Ginkel 2011).

These causes are generally characterised by high nutrient concentrations. Prolonged periods of stagnation, combined with favourable temperatures, high concentrations of oxygen and proper light regimes, all encourage the increased primary growth of algae and macrophytes. Agriculture is one of the major causes contributing to the eutrophication of surface waters. The extensive growth of nutrients in the water body impacts upon the composition and the functioning of the naturally occurring aquatic biota (Oberholster et al. 2009; van Ginkel 2011).

Inputs of major nutrients include both inorganic (ammonium, nitrate, nitrite, phosphate and silicate) and organic forms (dissolved organic and particulate matter). The accelerated population growth, as well as an increase in food production, results in major landscape changes and in turn increases sewage discharges and runoff from cultivated fields and pastures and settlements (Glibert et al. 2005).

The large increases in the application of chemical fertilisers, started in the 1950s, have also contributed significantly to eutrophication all over the world. Thus, the application of both nitrates and phosphates as components of fertilisers is of major concern. The increase in sewage discharges has also resulted in the eutrophication of water bodies as the sewage also contains high levels of nutrients such as phosphates and nitrates and can lead to the 'death' of a river, lake and even a sea (Glibert et al. 2005).

Eutrophication affects the microbiota of adjacent waters and is recognised as one of the important factors that contribute to habitat change, as well as to the geographical and temporal expansion of some harmful algal blooms (Smayda 1990; Glibert et al. 2005). The increase in phosphate and nitrate levels is accompanied by an increase in rapid algae growth. After the event of an algal 'bloom', the decomposing algae remove the dissolved oxygen from the water which leads to the death of fish and other organisms that need the oxygen dissolved in the water (Glibert et al. 2005; Mendiondo 2009).

An increase in the nutrient inputs thus leads to an increase in the incidence of nuisance blooms of blue-green algae, in turn leading to increased water turbidity, the development of organic and nutrient-rich sediments, and a loss of oxygen from the basal water flowing along the river bed. These processes lead to an acceleration in the nutrient-recycling processes and changes in the food web structure of the water body. The stocking of exotic fish species, as well as over-fishing, also exacerbate the eutrophication process (Glibert et al. 2005; Mendiondo 2009).

Eutrophication occurs right across the world in a variety of locations, as in North America's Great Lakes, in Kingston Harbour in Jamaica, and in many of the rivers of Eastern Europe. The anthropogenic impacts associated with eutrophication include the fouling of boats, as well as structures by algal growth, a loss in aesthetic appeal, and economic damage to property, all as a result of excessive macrophytic growth. The eutrophication of water also impacts upon the taste and odour of drinking water, increases the potential for trihalo-methane production, and lastly, raises the costs and compounds the technical difficulties of treating water (Glibert et al. 2005; Mendiondo 2009).

South Africa's climatic conditions, in combination with various other factors, have resulted in large-scale changes to aquatic ecosystems and the eutrophication of rivers and water storage reservoirs. The main factors that affect these water resources are the discharge of treated and untreated sewage effluent as a result of overloaded sewage treatment plants, excessive nutrient loads in return flows from agriculture, the modification of river-flow regimes, as well as changes in land use or land cover patterns (DWS 2002; Oberholster and Ashton 2008; CSIR 2010).

Eutrophication is clearly visible in dams such as the Hartebeespoort Dam in North-West province as well as within certain parts of the Upper Vaal WMA such as the Barrage Reservoir and some areas within the Blesbok Spruit. Nutrient-rich effluents have been released from the waste water treatment works and from underserviced areas and agricultural runoff. As more people move into this urban area, and are connected to the waterborne sewage systems, which discharge their wastes into waterways, this situation will be aggravated (van der Merwe-Botha 2009).

Eutrophication of freshwater resources needs to be taken seriously in South Africa as this country has limited freshwater resources. The eutrophication of water bodies also involves the production of cyanotoxins, which pose potential health risks and hold financial implications as attempts are made to control these noxious macrophytes (van Ginkel 2011).

It has been estimated that eutrophic conditions exist in one in five of 75 major impoundments and in 18 of 25 major river catchments. Cyanobacteria, including Microcystis and Anabaena species, are present in all major impoundments at levels dependent on the trophic state. Poisonings of domestic and wild animals by cyanobacterial toxins are geographically widespread and occur frequently which pose an increasing threat to the supply of safe drinking water to the whole population of South Africa. Eutrophication and cyanobacterial blooms serve as an economic burden on South Africa in the following manners:

- Increased costs associated with water treatment;
- Negative effects on water-side property values;
- Recreational and tourism losses as a result of users' negative perceptions of water quality;
- Negative human health impacts from poor water quality including diarrhoea, cholera and waterborne diseases;
- Animal fatalities;
- Poor aquatic ecology negatively affecting ecosystem services;
- Reduced biodiversity and proliferation of invasive species; and
- Increased cost of management and control of aquatic macrophytes (e.g. water hyacinth).

The economic cost of eutrophication is likely to extend to hundreds of millions of rands per year, being borne across all levels of society, but particularly affecting the livelihoods and health of the poor and vulnerable. Thus, the eutrophication of the freshwater resources in South Africa impacts upon the economic, environmental, social and health sectors of the country.

6.4 Agro-chemical Contamination

Agro-chemical contamination of water bodies is a major threat within the Upper Vaal WMA as the WMA is dominated by agricultural activities. Agro-chemicals are chemicals used primarily by the agricultural sector for raising the productivity levels of crops. These chemicals include pesticides, which include insecticides, fungicides, herbicides, as well as fertilisers. Pesticides are thus a mixture of substances which are used to prevent, destroy, repel or mitigate any pest. The transferral of these agro-chemicals into aquatic environments affects the environment by degrading the quality of the water (Dabrowski et al. 2001; Deelstra et al. 2011).

Agro-chemicals enter the water body through various pathways. These pathways include atmospheric transport/drift, leaching through the soil profile, as well as surface runoff (Dabrowski et al. 2001; Deelstra et al. 2011). The behaviour of the agro-chemicals is also dependent on environmental conditions such as the following:

- The method of applying chemicals (in the form of fertilisers, insecticides, herbicides, etc.);
- The agricultural farming system;
- The presence of an irrigation system;
- The soil types and their properties;
- The topography; and
- The rainfall.

The growth in the world's human population has been accompanied by an increase in the use of agro-chemicals—to protect crops and raise crop production levels. Agricultural activities are recognised worldwide as making a leading contribution to non-point source pollution. Approximately 2.3 million tonnes of industrial pesticides are used annually and have resulted in higher crop yields and more secure and reliable food sources for the growing population. Agro-chemical contamination, especially in the form of pesticides, has been rated as one of the world's most toxic pollution problems. The misuse of pesticides has increased over the past decades and has resulted in numerous environmental pollution and human health risks. It is estimated that approximately 2.5 million people across the world are at risk of pesticide pollution (Dabrowski et al. 2001; Deelstra et al. 2011).

Agricultural production is among the top agro-environmental concerns (Qui 2005). Annually, approximately 4.6 million tonnes of chemical pesticides are sprayed across the world into the environment. It is estimated that approximately 500 pesticides have mass applications, with organo-chloride pesticides, some herbicides and pesticides containing mercury, arsenic and lead which are highly toxic to the environment. Only 1% of the pesticides that are sprayed are effective. The other 99% are released to non-target soils, water bodies and the atmosphere. It is estimated that 98% of the insecticides used in the agricultural process do not quickly degrade at the point of application but that they enter the larger environment through rain and irrigation runoff, spray carry-over or residue retention on food crops (Dabrowski et al. 2001; Deelstra et al. 2011).

Farmers use insecticides to fight invasive insects and pests that may be harmful to crop quality and yields. Insecticides enter water bodies and rivers through surface runoff from fields, as well as, but to a lesser extent, during application, when they drift into the water. These agro-chemicals can also enter water bodies through contaminated groundwater, as well as through rainfall. It is estimated that the use of insecticides will increase over the world since the increasing temperatures accompanying climate change will affect insect migrations and cause reproduction patterns to change. This will force the agricultural sector to use more insecticides and other types of pesticides in order to fight invasive organisms and to protect crops (Dabrowski et al. 2001; Deelstra et al. 2011, Zhang et al. 2011).

The contamination levels in numerous central and southern European countries have been intensifying over the past two decades and the largest increases in contamination are expected to take place in areas that have low agricultural pesticide pollution levels at present. The increase in the use of insecticides will have devastating effects on biodiversity. As farmers try to fend off invading insects, the contaminated water will kill the native species that are part of the food chain for birds, fish, as well as other stream organisms (EurActiv 2011). Water bodies that are situated close to croplands are generally polluted by agro-chemicals (Zhang et al. 2011).

Pesticides cause numerous diseases such as cancer and even death. Chen et al. (2004) established that the occurrence of breast cancer is linearly correlated with the frequency of pesticide applications. For instance, DDT and its derivative, DEE, are likely to cause breast cancer (Zhang et al. 2011). The common health effects of pesticides include skin irritations, respiratory and pulmonary problems, vision loss, damage to nervous and immune systems, birth defects, the disruption of the hormonal system, cancer, and in some cases, death (Harris and McCartor 2011).

Water quality parameters such as nitrate and phosphate concentrations may be used as indicators to establish the extent of pesticide pollution. However, other water quality issues are also associated with these. The significance of pesticide pollution related to public health in South Africa has received very little attention from policy-makers and regulators. This lack of attention is attributed to the challenges associated with the monitoring of pesticides in South Africa. These challenges or difficulties include high costs related to analysis—in the form of analytical equipment, a lack of laboratory or technical skills, and lastly, inadequate institutional capacity (London et al. 2005; Maharaj 2005).

The absence of a regulatory framework, water standards and monitoring data for pesticides in South Africa could result in the inability of the country to address potential public health matters. Marginalised and impoverished groups in the country are usually the worst affected by environmental pollution from pesticides (London et al. 2005; Maharaj 2005). Thus, since agro-chemicals could cause the eutrophication of freshwater bodies, they should be considered to be important and need to be carefully analysed in the South African context.

6.5 Industrial Effluent Pollution

Industrialisation has been described as the cornerstone of all development strategies over the world as a result of its contribution to economic growth and human welfare. Even though industries contribute significantly to the economy, they carry inevitable costs and problems in terms of the pollution of the air and water resources. All industries, whether large or small in size, produce dirty waste water that affects the environment, as well as the human population. In fact, industrial effluent can be defined as any waste water that is generated by any industrial activity (Kanu and Achi 2011; Lokhande et al. 2011; Walakira and Okot-Okumu 2011; Gyawali et al. 2012).

Waste water from industries includes processed wastes from manufacturing, washing waste water, relatively uncontaminated water from heating and cooling operations, as well as sanitary wastes generated by the workers. Industrial waste water has its source in industries that are ‘wet’ by nature and which require large volumes of water for the processing and disposal of waste, thus causing these industries to be located close to water bodies. Those water bodies situated close to industrial areas are especially affected by the disposal of waste, which in turn alters the physical, chemical and biological nature of the water body. The Vaal River Barrage, Blesbok Spruit and Mooi River catchments are prime examples within the Upper Vaal WMA of the various negative effects accompanied with the disposal of industrial and mine wastes. It can thus be stated that pollution by industrial effluent is the most common source of water pollution in the present day. In fact, the pollution trend is increasing annually with an increase in the number of industrialised countries (Kanu and Achi 2011; Lokhande et al. 2011; Walakira and Okot-Okumu 2011; Gyawali et al. 2012).

The sources of industrial effluent pollutants include the pharmaceutical industry, the soap and detergent industry, the paper mill industry, textile mills, breweries, tanneries, soft drink manufacturers, the chemical industry, industrial estates, as well as industrial and municipal dump sites. Wastes enter water bodies in solid and liquid form and are mostly derived from the products of agricultural, industrial and domestic activities. These affected water bodies are thus major receptacles for treated and untreated or partially-treated industrial wastes, which cause high levels of pollution. Industrial effluents are characterised by abnormally high levels of turbidity, electrical conductivity, chemical oxygen demand, total suspended solid and total hardness. The increase in industrial effluents is associated with an increase in the biological oxygen demand, the total dissolved solid and total suspended solid levels, and in toxic metals such as cadmium, chromium, nickel and lead, as well as in *Faecal coliforms*. The degradation in the quality of the water makes the water unsuitable for drinking purposes, for irrigation and for aquatic life (Kanu and Achi 2011; Lokhande et al. 2011; Walakira and Okot-Okumu 2011; Gyawali et al. 2012).

Urban areas also contribute to industrial effluent pollution with the careless disposal of industrial effluents and other wastes (Phiri et al. 2005). The increase in population, with the accompanied growth in industries, is also placing pressure on areas with limited water resources. Most urban cities in developing countries have access to piped water. However, several still rely on borehole water for domestic use.

Most rivers in developing countries of the world are the end points for effluents discharged by industries. Groundwater is also polluted by inadequately controlled and/or untreated industrial effluents. As a result, both boreholes and rivers in these affected areas generally contain poor quality water and the populations that consume the contaminated water could contract diseases such as bilharzia, cholera, diarrhoea and others (Phiri et al. 2005; Walakira and Okot-Okumu 2011). Industrial effluents could be associated with microbial pollution, as well as eutrophication, and should, therefore, also be awarded the necessary attention in South Africa.

6.6 Salinisation

Salinisation is described as a process whereby the salinity of inland waters increases either naturally or through anthropogenic activities. Natural salinisation is mostly restricted to closed drainage basins located in the arid and semi-arid regions of the world. These areas are also characterised by anthropogenic salinisation (Williams 1999; Rengasamy 2006).

The process involves the movement of salts and water in soils during seasonal cycles and during interactions with groundwater. The natural sources of salts include rainfall, aeolian deposits and mineral weathering. Stored salts are often released into the environment by surface water and groundwater. Anthropogenic activities might also release additional salts into the system (Pitman and Lauchli 2002). Salinisation is caused by changes in the land use and irrigation practices in a catchment area, as well as through the discharge of effluents such as brine from mines into catchment areas (Williams 1999). Irrigation salinisation is associated with increased salt levels in the groundwater which reflect the change in balance between the inputs of water and salts, as well as the changes in water and salt drainage. Salinisation is usually characterised by waterlogging, which can lead to saline seepages into low-lying areas (Pitman and Lauchli 2002; Rengasamy 2006).

Salinisation increases with the demands of the human population and impacts upon the water resources in drylands. The ecological effect includes a reduction in biodiversity and in the development of a halo-tolerant biota. The economic impacts are also significant, especially when the water resources involved provide the only permanent and reliable source of water for the region's population. An increase in the salinity levels renders the water useless for agricultural purposes and also for economic purposes such as drinking water and industrial supplies, when the salinity concentration is higher than 1 g/L (Williams 1999; Pitman and Lauchli 2002). Salinisation also affects the viability of the affected water resources and with the increase in the area of dry land which is to be expected with climate change and the extension of the drylands, the salinisation of water resources will intensify (Williams 1999).

The significance of salinisation caused by human activities is increasing and the world is beginning to recognise the threats and impacts that it poses at the national level.

Salinisation is a persistent water quality problem in South Africa and is mainly caused by the discharge of municipal and industrial effluent, irrigation return flows, urban storm water runoff, the surface mobilisation of pollutants from mines and industries, as well as seepage from waste disposal sites. The salinisation of irrigation water contributes to soil degradation, which in turn affects commercial and subsistence agriculture and hence, food security directly. The salinisation of some of the country's water resources has reduced the yield and quality of the crop, has intensified scale formation and corrosion in domestic and industrial water systems, has increased the need for pre-treatment, and has caused changes in the community structures of the affected aquatic biota in the system (CSIR 2010; van Rensburg et al. 2011; de Lange et al. 2012).

The increase of nitrate concentrations in the groundwater poses elevated risks of methaemoglobanaemia to infants who drink formula feeds using water drawn from contaminated sources in certain areas of the country. High fluoride concentrations have caused bone and dental fluorosis in children and adults (CSIR 2010; van Rensburg et al. 2011).

The high-risk areas for salinisation in South Africa are the lower Vaal River, the Breede, Crocodile and Olifants Rivers. Furthermore, the removal of salts from the Vaal River system has increased and been accompanied by an increase in treatment costs. The salts in this case are derived from the AMD from gold and coal-mining activities on the Witwatersrand, as well as from agricultural runoff (van der Merwe-Botha 2009; CSIR 2010).

6.7 Mining Effluent Pollution

The USA Environmental Protection Agency concluded in 1987 that 'in terms of ecological risk' problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion. The release of mining waste can result in the profound, generally irreversible destruction of ecosystems (EEB 2000). Mining effluent includes liquid wastes from mining operations, especially those involved in extracting ores which contain sulphides such as nickel, copper, iron, zinc, cadmium, lead and coal (if pyrites are present). These mining operations may produce acidic and metal-bearing solutions which are attributed to the natural oxidation of sulphides through exposure to air and water. The potential sources of water pollution from mining operations include drainage from surface and underground mines, as well as runoff from beneficiation and surface runoff (CSIR 2010).

The key pollutants and sources in terms of mining effluents globally affect over 7 million people across the entire globe. Artisanal gold mining, which results in mercury pollution, is rated as the most toxic pollution problem in the world. Other sources and key pollutants within the top 20 include mining and/or processing associated with mercury, lead, arsenic, cadmium and cyanide pollution, and uranium mining and ore processing which are associated with radio-nuclide pollution (Deelstra et al. 2011).

The combination of acids and heavy metals has had severe effects on the ecology of the affected water courses. These metals enter and bio-accumulate in the food chain and could cause the acidification of the water body. AMD is contaminated waste that was generated through mining activities during and subsequent to the operational period. AMD can be problematical for both surface water bodies and the groundwater store when drainage from surface workings and from waste rock stock piles and tailings deposits enters a water body or percolates down through the soil and rocks to eventually reach the upper limit of the water table (CSIR 2010). The Upper Vaal WMA is characterised by numerous mining operations especially within the Vaal Dam and Waterval catchment, the Vaal River Barrage, Blesbok Spruit and the Mooi River catchments. The Mooi River catchment is of major concern as acid mine water is decanting throughout the whole Western Basin which have been accompanied with widespread negative environmental and social impacts within the region. Furthermore, it is estimated that acid mine water is also now decanting from the Central Basin which will consequently worsen the already poor water quality conditions within the Blesbok Spruit and Vaal River Barrage catchments.

Mines make use of dangerous and toxic chemicals such as sulphuric acid or cyanide (leaching) or organic reagents (flotation) in the mineral separation processes and are serious sources of contamination if appropriate control systems have not been put in place. The waste water generated by mines also contains large amounts of suspended solids, which originate from the ore itself, waste material or from surface installations (CSIR 2010).

AMD has a profound impact on the socio-economic conditions of the populations residing in and around the mining site, as well as costly environmental impacts. The waste water consists of substances with high salinity levels and which contain toxic elements and salts. These solids affect the aquatic flora and fauna and also physically choke local waterways and water bodies. Mining effluent is responsible for the degradation of soil quality and aquatic habitats and allows substances containing heavy metals to seep into the environment. Excavations influence the surrounding hydrology and may lead to more rapid seepage into the groundwater, resulting in the drying up of nearby streams and wells (McCarthy and Pretorius 2009).

Mining effluent pollution will thus continue to be among the top ranked water quality problems in the world as well as South Africa if appropriate control measures continue to be ignored or are found to be totally absent. As mining effluent contributes to the acidification of freshwater resources, it is also very important in the South African context.

6.8 Acidification

Acidification is commonly associated with atmospheric pollution arising from anthropogenic activities which release sulphur and nitrogen as NO_x and ammonia respectively. Acidification of freshwater was first identified as a problem in Scandinavia during the early 1970s. Water bodies that are generally regarded as acidified generally contain nutrient-deficient waters that drain onto unreactive geological formations (Moiseenko 1994; Schopp et al. 2003).

The acidification of water bodies can also be caused naturally. Natural acidic settings include those associated with the oxidisation of sulphide-rich mineral deposits of copper, zinc, lead, argon and irons. Volcanic eruptions eject SO_2 and NO into the atmosphere when oxidation takes place and forms H_2SO_4 and HNO_3, both of which support aerosol formation, and cause the acidification of local rainwater. The oxidation of organic matter such as petroleum and peat can also lower the pH of the water body through the addition of organic acids. Thus the three natural causes for the acidification of freshwater bodies are podzolisation, the natural actions of atmospheric carbonic acids, as well as the formation of organic acids through the podzolisation of peat or humus (Landers et al. 1994).

Unusually low levels of the pH in freshwater bodies are, however, most commonly associated with parts of the landscape that are being disturbed by human activities rather than through these natural processes. Land use changes through anthropogenically-induced processes include the introduction of livestock into a catchment area, the use of nitrate-containing fertilisers, an increase in drainage efficiency, the dry deposition of air pollutants, and lastly, the wet deposition of sulphuric and nitric acids (Rice and Herman 2011).

The AMD that arises in coal- and metal-ore-mining regions also contributes to the acidification of freshwater bodies. Thus, the acidification of fresh surface water can be stated to be due to the direct deposition of pollutants into the water body or, more commonly, through runoff and soil throughflow from the surrounding catchment area (Psenner 1994). Once again the Mooi River catchment is a prime example of the results of the acidification of water due to the decanting of acid mine water from mining operations which were not properly decommissioned within the Western Basin of Johannesburg.

The effects of the acidification of freshwater include the release of toxic metals into the water body, the retention of phosphorus, changes in freshwater fauna and flora, and carbonic source changes from a carbonate to carbon dioxide. Owing to the precipitation of humic substances, acidification apparently causes water bodies to be clearer and bluer. The diversity in the composition of the water in a body of water declines considerably and many of the algal species and macrophytes in and around the water body decrease in number. Soft-bodied animals such as snails and crayfish are among the first to be affected and are usually the first sign of acidification. All the life stages of fish are affected and the death of adult fish is primarily caused by the release of toxic metals such as aluminium at low pH levels. The acidification of freshwater resources is recognised as one of the main global impacts on freshwater bodies. The acidification of freshwater is no longer limited to the northern hemisphere and now affects all industrial regions of the world (Psenner 1994).

The freshwater resources of South Africa are relatively well-buffered. However, human-induced acidification from industrial effluents, mine drainage and acid rain could cause the pH of these water resources to decrease over time. The decline in pH can be associated with the mobilisation of heavy metals such as iron, aluminium, cadmium, copper, mercury, manganese, nickel, lead and zinc which can bio-accumulate in fruits and crops (DEAT 2008; CSIR 2010).

Gold mining that took place in the Witwatersrand area has resulted in the heavy contamination of groundwater in the region with elevated heavy metal concentrations and acidified water. The contaminated groundwater is currently being discharged into the streams of the area and is contributing 20% to the total stream discharge. Coal-fired power stations also contribute to the acidification of the country's water resources through the wet and dry deposition of acid rain (CSIR 2010; Potgieter 2010).

The Olifants River catchment area in Mpumalanga is a good example of the acidification of a water resource. This area has been significantly affected by AMD from the surrounding coal mines, leaving the water unpotable for human consumption and unusable for other functions. The sulphate levels (in solution) are steadily increasing and with toxic constituents such as copper, arsenic and chrome, there have been recent fish and crocodile deaths in the Kruger National Park (de Villiers and Mkwelo 2009; Groenewald 2012).

6.9 Sediments and Soil Erosion

Although not listed as a significant global water quality issue, soil erosion is a serious problem in South Africa and, owing to human impacts, the erosion rates have increased considerably over the past decades. The annual soil loss in South Africa is estimated at 300–400 million tonnes per annum. This amounts to nearly three tonnes for each hectare of land. Furthermore, it is estimated that for every tonne of maize, wheat, sugar or any other agricultural crop produced, South Africa loses on average 20 tonnes of soil. Soil erosion is thus a serious environmental problem. It has been estimated that it will cost the country approximately R1000 million to replace with fertilisers the soil nutrients that are carried out by our rivers to the oceans each year (van der Merwe-Botha 2009).

The deposition of these eroded sediments results in a loss of reservoir storage capacity, damage to agricultural land and crops, enhanced water treatment costs, as well as various impacts on the aquatic environment. As a physical pollutant, sediment impacts upon the water body receiving it by causing high sedimentation levels and raising the turbidity levels. It disrupts the aquatic biodiversity quite considerably as it causes the water body to become unacceptable in terms of both aesthetic and economic factors (Braune and Looser 1989).

Radionuclide and heavy metals, the legacy of unregulated gold mining and high density populations living in close daily contact with dust and sediment arising from mine tailings, have contaminated the local water resources. Portions of Soweto and the East and West Witwatersrand, all located within the Upper Vaal WMA, are textbook examples of this (van der Merwe-Botha 2009). Soil erosion and sedimentation are thus significant problems confronting South Africa and will continue to become more threatening as the country's population grows in number.

6.10 Specific Water Quality Challenges Within the Upper Vaal WMA

As previously described, the Upper Vaal WMA is highly developed, with the quality of the water varying from poor in developed regions to good in less-developed areas. The water quality in the main rivers, as well as in the tributaries downstream of the Vaal Dam, is affected as a result of urban and industrial return flows and intensive mining activity.

The Wilge River catchment area (refer to Fig. 5.4), is described as largely pristine with local water quality problems related to waste water from treatment works and from sewage reticulation systems, as well as from urban runoff. The rapid increase in waste water from urban areas has been associated with stormwater and industrial water management problems, especially in the Phuthaditjhaba industrial complex, where extensive soil erosion is also taking place. Most of the rivers located in this catchment area are used for carrying the water transferred from the Lesotho Highlands Water Project to the Vaal Dam and have thus caused soil erosion problems. Should the water transfers not be properly managed and remediated, there is the distinct possibility that an increase in the volume of water transported could lead to increased soil erosion and sedimentation (DWS 2004a, b).

The Grootdraai Dam tertiary catchment area, located within the Vaal River secondary catchment (refer to Fig. 5.3), is being dominated by impacts associated with coal-mining activities in the area. Both the abandoned and operational mines in the Ermelo district, as well as those located in the Leeu Spruit sub-catchment area (refer to Fig. 5.5), could contribute to salinity problems. The development of further coal reserves in the area could therefore threaten the current quality of the water in the sub-catchment area which is good. The eutrophication problems occurring in this sub-catchment area are mainly due to waste water from waste water treatment plants and landfill sites. The agricultural activities in the region could also contribute to excessive nutrients and sediment loads in the river system (DWS 2004a, b).

The Vaal Dam and the Waterval catchment area (refer to Fig. 5.4), are characterised by salinity, nutrient and microbial pollution. The Sasol coal mining and synthetic fuel industry dominates this sub-catchment area, causing salinity problems. The gold mines, located in the Waterval catchment area, also contribute to salinity, as well as to possible acidification. These pollution problems arise from both point and diffuse sources. The diffuse sources include effluent from ash dams, and surface runoff from mines and industrial complexes. Nutrient pollution is related to discharges from waste water treatment plants, poorly managed sewage systems and return flows from urban areas (DWS 2004a, b).

The Suikerbosrant and Klip River sub-catchment areas in the Vaal River Barrage secondary catchment area in Gauteng Province (refer to Fig. 5.5), are also characterised by salinity and eutrophication. The threats that they pose to public health are mainly due to the mining industry. The withdrawal of water from Grootvlei is causing seepage from the tailings dams and industrial discharges from South African Pulp and Paper Industries SAPPI. Waste water treatment plants also contribute to the salinity problems, as well as to eutrophication, since they discharge waste water into the Blesbok Spruit (refer to Fig. 5.5). The return flows from the densely populated urban areas also contribute to the high levels of nutrients and sediments which are deposited in the river system (DWS 2004a, b).

The quality of the Blesbok Spruit catchment's water resources has declined immensely due to discharge of mining effluent, sewage as well as the other pollution associated with the urbanisation, industrial and agricultural growth over the past decades within the catchment. It was consequently put on the Montreaux Record in 1996 and is now characterised by poor water quality, a continuing decline of ecological health and a declining bird population (Haskins 1998; Dini 1998; Schoeman and Steyn 2000; DWS 2006). The wetland has been placed on the Montreaux Record due to changes that have occurred in the ecological character as a result of technological developments, pollution and other human interferences. The ecological health of the Blesbok Spruit catchment and its associated ecological systems is of prime importance as it has cumulative negative environmental impacts and significant human health effects for the region as well as the other receiving catchments within the Upper Vaal WMA.

Outbreaks of blue-green algae and water hyacinth, as well as raised salinity levels, have been reported in the Vaal River Barrage catchment area. The Vaal River Barrage receives inputs from all of the sub-catchments upstream of the Vaal Dam such as the Suikerbosrant which affect the quality of its water. The S.A. Mittal complex, located in this sub-catchment area, is a diffuse source of pollution, contributing to the degradation of the quality of the water in this region (DWS 2004a, b; Tempelhoff 2009).

The Mooi River catchment area (refer to Fig. 5.6), located downstream of the Vaal River Barrage has been experiencing water quality problems in the form of radio-activity. Radio-active pollution is due to the tailings dams in the area, as well as to tailings that have been washing into the streams over the past decade. The catchment area is also characterised by eutrophication and public health problems owing to stormwater runoff and discharges from waste water treatment plants. Salinity and acidification problems are also due to mining activities and seepages from tailings dams (DWS 2004a, b; Tempelhoff 2009).

Eutrophication, salinisation, microbial pollution, sedimentation and acidification are thus all significant problems affecting the quality of the water in the Upper Vaal WMA.

The water quality of South Africa is thus plagued by various problems which will continue to increase as long as the management of the various WMAs is inefficient or ineffectual and as long as uninformed decisions are taken regarding further development in the country.

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Chapter 7
Water Scarcity and Other Significant Challenges for South Africa

South Africa is currently facing a growing water crisis due to dwindling water supply and a widespread decrease in water quality. Water shortages are predicted for the majority of large urban areas and interventions will be needed. Urbanisation is accompanied with new needs from housing developments, densification, informal settlements and shared services. Even though a number of households are served with water connections, the growth has left some households without effective services on site. Currently a large percentage of the country's water is being lost. Climate change will impact the water resources of the southern African region by the increasing variability of rainfall. Water shortages are expected to affect 50–100 million of the region's population by 2050. In terms of South Africa, climate change will pose significant risks to the country's natural assets as well as its human population. South Africa will find itself in a precarious position regarding its freshwater resources within the near future. The increase of water shortages will cause possible conflicts between economic sectors such as agriculture, mining, energy, domestic/municipality as they fight for their share of this declining scarce resource. Focus is placed on water scarcity within the country as well as possible influences of climate change, future water demand and possible conflicts.

7.1 Introduction

Even though there have been dramatic improvements since 1994 with 91% of the population having access to basic service levels, there is still a considerable amount of the population still needing safe water supplies. Backlogs exist in formal historical basic water supply needs pervasive in the Eastern Cape, KwaZulu-Natal and parts of Limpopo and North West provinces. Constraints include topographical features in KwaZulu-Natal, water stress in Limpopo and limited surface water in North West province. The bulk of these backlogs are mainly attributed to the lack of major investment in water supply systems which cause the available

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_7

water not to reach people due to operating challenges. In some cases, such as in the Limpopo and Mpumalanga provinces, backlogs are attributed to settlements being located in water scarce areas which are disadvantaged by a lack of water resources and bulk infrastructure.

Water savings achieved from addressing the indicated water losses in the different sectors can therefore be invested into these regions with proper investment, planning and implementation to decrease social water inequalities. However, present infrastructural inadequacies need to be addressed before water savings are invested in to avoid further water losses through leakages and pollution (Seago and Mckenzie 2012; DWS 2014).

7.2 Water Scarcity

Water shortages are predicted for the majority of large urban areas and interventions will be needed here as well. Urbanisation is accompanied with new needs from housing developments, densification, informal settlements and shared services. Even though a number of households are served with water connections, the growth has left some households without effective services on site. Furthermore, many water and waste water works have reached their designed capacities, are in a poor state or are not functioning properly which results in major wastewater spillages and immense environmental and health impacts. Therefore, before potential water savings can be invested in urban areas, investments should first and foremost be made to address the current water and wastewater treatment infrastructure backlog. Implementing water savings in these areas will be futile as it will be accompanied with further water costs and losses due to pollution caused by wastewater spillages (Seago and Mckenzie 2012; DWS 2014).

Currently a minimum of 31% of South Africa's water is being lost within the mentioned sectors. This percentage of water savings should be invested into the reduction of inequalities in the access to potable water will ensure that the country reaches their target of every person having access (i.e. address the other 9% not having access) and consequently assist the country in achieving its constitutional right of a minimum of 25 L of water per person per day. Water savings should therefore be re-allocated to other sectors or activities within certain regions where water availability is a dominant problem.

It is important to note that of South Africa's 120 river signatures, 82% are threatened, 44% are critically endangered, 27% are endangered, 11% are vulnerable and 18% are least threatened (Fig. 7.1) (SANBI 2007). Water quality is therefore a major issue which needs urgent attention as it plays a major role in current and future water scarcity.

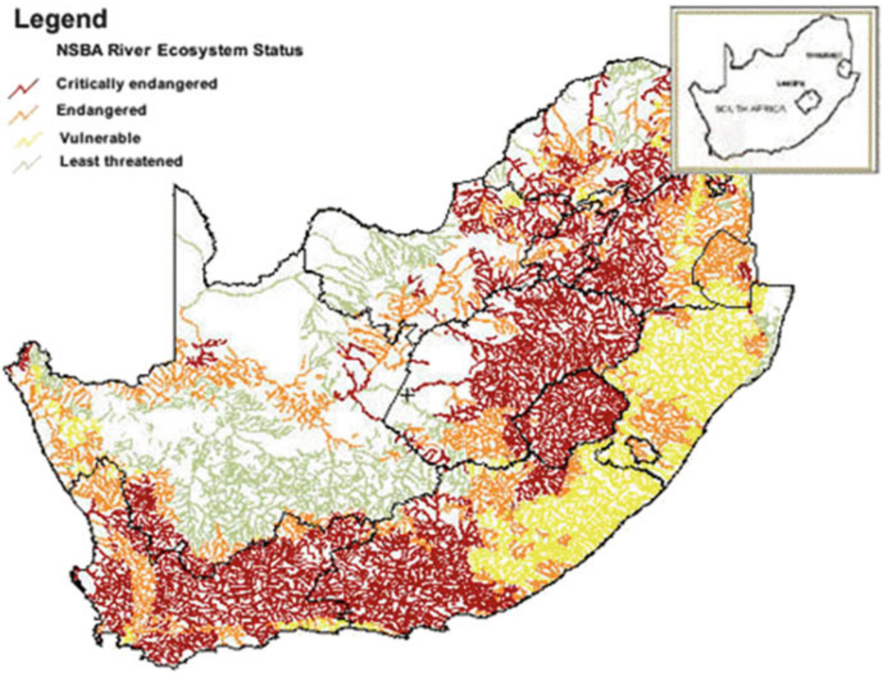

Fig. 7.1 River ecosystem status for South Africa (SANBI 2007)

It is therefore of prime importance that water savings be invested into these vulnerable ecosystems in terms of water availability and quality. The determined water savings therefore also needs to be invested into the ecological reserve to ensure ecological health but also the future sustainability of the country's water resources.

The pollution of the country's limited water resources as well as the allocation of 95% of its water resources are inter-related problems and need to be addressed as such. The reduction of water demand, water losses as well as the implementation of water efficiency measures will assist the country to achieve water savings and decrease the current dependencies of different sectors on its limited water resources. This will in turn especially assist in the avoidance or minimization of water shortages during droughts and protect the country against losses which may inhibit economic growth. The increase of water efficiency in all sectors should therefore be placed at the forefront to ensure sustainable water use as well as to assist the country in lessening its exposure to the effects of drought as well as in adapting and dealing with the consequences of climate change. The incorporation of water efficiency measures will also contribute to the resilience of sectors in terms of water scarcity within the country by decreasing the possible influence of future droughts on their operations. Therefore building an overall resilience towards water related issues.

7.3 Possible Influence of Climate Change

As discussed in Chap. 3, climate change will have varied effects over the globe. Different areas will therefore experience different effects of climate change. For example some areas of southern Africa will experience a decrease in rainfall and more wind, whereas other areas may experience an increase in rainfall as well as an increase in temperature and humidity. The IPCC's fourth assessment report of 2007 predicted that the southern African region may experience a 3.4 °C rise in annual temperature, a 23% decrease in winter rainfall and a 13% decrease spring rainfall in future i.e. 2080–2099. It should be noted that these predicted changes will however not occur uniformly across the region as it is predicted that the western parts of South Africa will become drier, whilst the eastern parts of South Africa will become more wet and central Botswana will experience a much rapid increase in temperature than the surrounding areas (IPCC 2014).

The predicted impacts of climate change on southern Africa's water resources also vary across the region. Water resources will mainly be impacted upon by the increasing variability of rainfall as well as rising sea levels. It is predicted that both surface water and groundwater will decrease, evaporation will increase leading to soils becoming more salty. Water shortages are expected to affect 50–100 million of the region's population by 2050. More frequent extreme weather events such as floods will occur. Even though floods may relieve water shortages, it will lead to damaging infrastructure and more water-borne diseases. This will ultimately have immense implications for the region's food security and affect human health and natural ecosystems negatively (IPCC 2014).

In terms of South Africa, climate change will pose significant risks to the country's natural assets as well as its human population. The country has experienced gradual but steady climatic changes. Over the last 60 years, temperatures have risen significantly and it is predicted that this trend will continue with a rise of 1–2 °C expected in coastal regions and a rise of 3–4 °C expected in the interior by 2050. By 2100, it is predicted that temperature would rise by 3–4 °C at coastal regions and 6–7 °C in the interior. It is also predicted that rainfall patterns will also change however this change is a lot more variable and unpredictable. The increase in temperature will cause parts of the country to become much drier and will in turn decrease water availability and significantly affect human health, agriculture and other water-intensive economic sectors such as mining as well as the environment in general (Griffin 2012).

Climate change in the country will also be accompanied by an increased occurrence and severity of veld and forest fires, extreme weather events as well as floods and droughts. Sea-level rise will degrade the coast and coastal infrastructure and the mass extinction of endemic fauna and flora will greatly reduce the country's biodiversity with consequent impacts on ecosystem services (Griffin 2012).

This consequently places South Africa in a vulnerable position due to a large portion of the population still living in impoverished circumstances where informal settlements are located in areas vulnerable to extreme weather events and housing structures do not offer sufficient protection against these events. There is also a high rate of disease which places these impoverished populations at greater risk. Climate change will have socio-economic impacts such as affecting food security negatively as both agriculture and fisheries will face climate change related threats. The increase of temperature as well as the change in rainfall patterns will also affect ecosystems and population dynamics which could lead to a change of fauna and flora communities (Griffin 2012; Actionaid 2016).

Climate change will therefore be accompanied with implications on food security, employment, exports as well as tourism and may lead to tropical diseases such as malaria becoming more prevalent due to the increase of rainfall and temperatures. The increase of extreme weather events may increase the risk of cholera outbreaks or other water-borne diseases especially in informal settlements where sanitation facilities and water treatment infrastructure is lacking. The National Climate Change Response White Paper was consequently developed in an attempt to build South Africa's climate resilience in terms of the economy and its population as well as to assist in managing the country's transition to a climate-resilient, equitable lower-carbon economy and society (RSA 2011; Griffin 2012; Actionaid 2016).

The severe water pollution in multiple areas as well as the high levels of water loss and wastage, have exacerbated the pressure on the country's water resources. This in combination with the accompanied change in rainfall patterns and more

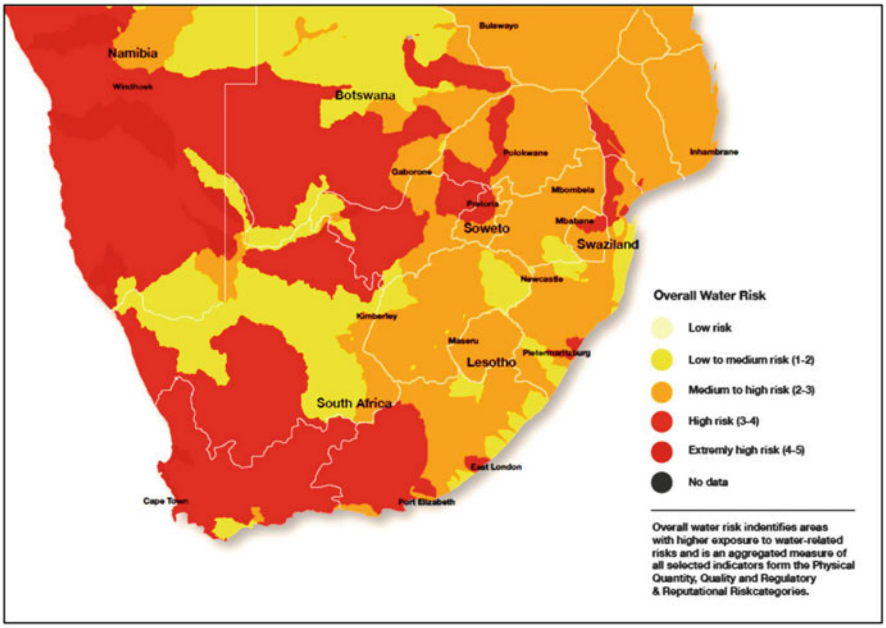

Fig. 7.2 South Africa's rating according to the Water Risk Index (Actionaid 2016)

intense and frequent weather events such as floods and droughts, have consequently placed the country alarmingly close to the water scarcity threshold and might be re-classified from being water stressed to water scarce in the near future. Figure 7.2 illustrates South Africa's rating according to the water risk index.

The increasingly hot climate has aggravated water shortages. This is mainly due to three times more water evaporating from dams and storage facilities than what falls as rain, making it a challenge to replenish water stores. Other influencing factors include the rise in electricity costs which hold implications for the cost of pumping water, rising purification costs as well as the significant investment which is needed to refurbish and construct new water infrastructure within the country.

7.4 Future Water Demand and Possible Water Conflicts

We can thus conclude that South Africa will find itself in a precarious position regarding its freshwater resources within the near future. The future water demand of the country indicates that there will be a gap of 17% between water supply and demand. Estimated water usage in South Africa for 2013 was between 15.6–16 billion km^3 a year and future demand projections are 17.7 billion km^3 by 2030 (Actionaid 2016).

At least 6 out of the 19 Water Management Areas in the country will not have sufficient water to meet demand by 2030. Areas which are predicted to face the biggest challenges are the ones supplying the largest cities within the country i.e. Johannesburg, Cape Town, Durban and Pretoria. The Berg Water Management Area which supplies Cape Town, will face a gap of 28% to meet future demand and the Institute of Security Studies have indicated in 2014 that the Government's current plan is not adequate to address the scale and severity of the problem.

The drought which the country is experiencing (2015–2016) have exposed the fragility of the region's water system and some engineers have warned that mass water-shedding (cutting off supply in times of critical over use and under supply), will have to be implemented by the government soon. Water-shedding will have drastic consequences for individuals, communities as well as industries and ultimately the country's economy. In November 2015, the global investment bank, Nomura International, reduced the 2016 growth forecast of the country by 3% on the basis of water restrictions limiting output which would compound negative inflation trends.

South Africa has been hit by a high number of social protests mostly focussed upon lack of service delivery especially in terms of water service delivery. These social protests tend to occur in working-class urban and peri-urban localities characterised by high levels of poverty, unemployment, inequality, relative deprivation, marginalisation and disjuncture's (including communication breakdown) between water services development planning at municipal and national levels and water use at local household and community levels, irrespective of the political party affiliation of local government. Other issues may include infrastructure theft, breakdown and obsolescence, and lack of financial budgets to repair existing infrastructure and/or develop new infrastructure to accommodate burgeoning demands offset by rapid urbanisation (Actionaid 2016).

The availability of freshwater resources within the country has come into the spotlight due to the recent drought. It is estimated that water-related issues have received more than 31,000 mentions in print, media, broadcast, online and social media coverage since January 2015. These mentions mostly focussed upon the financial and organisational implications of water shortages and drought on food production and prices. Most reporting was done on short term responses or addressing immediate consequences with the launch of various relief initiatives such as Operation Hydrate, Save Water Now and Project Thirst. However very little reporting has been done regarding the long-term solutions to the water crisis or what could happen if the situation was to become permanent (Actionaid 2016).

Current water conflicts are therefore occurring in the form of social protests where water service delivery is in the spotlight. However, the increase of water shortages due to the continued degradation of water resources, continued water leakage and wastage as well as the increasing effects of climate change will cause possible conflicts between economic sectors such as agriculture, mining, energy, domestic/municipality as they fight for their share of this declining scarce resource.

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Part III
Future Possibilities and Strategic Actions

Chapter 8
A Future Outlook: Improved Water Efficiency and Possible Strategic Actions for South Africa and the Upper Vaal WMA

Water scarcity or stress can be accompanied with social, environmental and economic implications. Water related risks have increased and have become significant in all spheres due to South Africa's water-stressed nature. However, even though water scarcity has been the most reported risk, very few sectors or organisations have measurable water use targets and a huge variability in the nature and ambition of targets are present. This in turn indicates a lack of urgency in terms of water related targets. A clear understanding of the real potential for reducing water losses is needed before measures are adopted or implemented to avoid costly and ineffective demand management strategies. Various water efficiency measures are available and can possibly be implemented and adopted by the various sectors within the country to promote proper water conservation and water demand management practices. These water efficiency measures however need to be both cost effective and enforced by relevant departments for the country and region to ultimately benefit from implementing water conservation and water demand management measures, targets and structures. Focus is placed on improved water efficiency measures within different sectors as well as possible strategic actions which will be necessary for improved water conservation and water demand management in the country and WMA.

8.1 Introduction

Water stress or scarcity is the most reported risk, followed by declining water quality, flooding and higher water prices. Two-thirds of all the anticipated risks are seen to have the potential to impact the business's direct operations or their supply chains within the next 5 years. Some South African businesses have reported exposure to recent water-related events and imminent risks which suggests a compelling case for immediate business action and strong engagement of investors in the Johannesburg Stock Exchange (JSE).

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_8

Water related risks have therefore increased and have become significant in all spheres due to South Africa's water-stressed nature. Short term and long term risks therefore need to be identified and be addressed with the implementation of appropriate measures or solutions (CDP 2012). However, even though water scarcity has been the most reported risk very few sectors or organisations have measurable water use targets and there is a huge variability in the nature and ambition of targets. This in turn indicates a lack of urgency in terms of water related targets.

Water scarcity or stress can be accompanied with social, environmental and economic implications. Tongaat Hulett South Africa, an agricultural and agri-processing business which includes integrated components of land management and property development, reported a loss of R7 million in 2011 due to drought in KwaZulu Natal specifically in terms of their sugar milling and refining operations. This is however just one example of the significant financial costs which companies and/or the country may incur due to increased water stress (CDP 2012).

Water is both a critical sustainability challenge due to increasing demand and a significant investment opportunity in terms of the investment or development of water efficiency measures and solutions which address current and future water related challenges. The country needs to place water scarcity at the forefront of its strategic planning due to the accompanied social, environmental and economic costs. Focus needs to be placed on water efficiency measures which can be implemented in the short term which are cost-efficient and other more expensive measures for the long term. As discussed in Chap. 4, it is possible to convert water losses into water savings which can be invested to improve a variety of aspects within South Africa with the implementation of water efficiency measures. This chapter will focus on possible solutions to the water crisis by looking at possible water efficiency measures which could be adopted and implemented within the different sectors with the incorporation of examples as well as look at what strategic actions would be necessary to improve water efficiency within sectors to ultimately lessen water-related risks and social, environmental and economic costs within the South Africa.

8.2 Improved Water Efficiency Measures

When deciding on water efficiency measures, the different nexus which exist needs to be considered. For example, new water infrastructure will require energy and needs to be carefully allocated in terms of new human settlements, agricultural irrigation and industrial and economic growth. We therefore need to keep the nexus which exists between water, energy and food in mind by integrating this into short and long term planning, with all sectors of society sharing the common vision rather than a short term scramble for water.

A clear understanding of the real potential for reducing water losses is needed before these measures are adopted or implemented to avoid costly and ineffective demand management strategies. The buy-in of different social sectors is also required to promote the consideration of the water, energy and food nexus when planning on adopting and implementing water efficiency measures. This is not an easy task and will require proper planning and implementation.

Although the situation in South Africa and the Upper Vaal WMA is challenging, as indicated in the previous chapters, the country does have good environmental legislation and good infrastructure which will continue to deliver if well maintained and upgraded when required. The increasing focus which has been placed on water by civil society, the public and private sector is also encouraging. In addition, other significant developments have also taken place within the water sector which drives improvement and includes the following:

- Increasing availability and affordability of water treatment technologies;
- The setting of water efficiency targets and emerging of best practices in all water use sectors;
- The development of the second National Water Resource Strategy in a consultative way, although seen as to be ambitious and somewhat controversial in places, have included considerations other than just the usual traditional technical aspects; and
- The increased willingness and proliferation of public private partnerships on water has also emerged but can be a challenging endeavour due to varied priorities (profits and growth), skills and perspectives.

It should be noted that even though these mentioned developments have been implemented there is still much room for improvement as water efficiency targets and emerging of best practices in all water use sectors have not taken place and the increased willingness and proliferation of public private partnerships on water is still lacking.

In addition, the cost-curve of South Africa also indicates that the country can implement a balanced solution to close its demand-supply gap with the application of a collection of cost-effective measures available across its supply network, agricultural efficiency and productivity improvements as well as industrial and domestic controls. The implementation of cost-effective measures will attribute to a significant source of savings and will consequently be accompanied with more productive water usage and increased energy efficiency across all sectors. The selection and implementation of these measures need to be localised to be able to provide the required specific economic and social needs of each particular region and sector (Seago and Mckenzie 2012; DWS 2014; World Bank 2014).

For example, the focus of water efficiency for approximately seven water management areas within the country will be focussed almost entirely on agricultural improvements whereas economic centres such as Johannesburg, Durban and Cape Town will focus more on industrial and domestic solutions. However cumulatively, the country's plan to double its power generation capacity by 2025 as well as the challenges brought by demand centres that are mostly geographically removed from additional supply will place immense pressure on its water resources and needs to be kept in mind.

There is therefore room for improvement across the different sectors in terms of improved water efficiency. Different water efficiency possibilities which could be implemented in the agricultural, industrial as well as domestic/municipal sectors now follows.

8.2.1 Agricultural Sector

The high degree of physical and economic water scarcity as well as the increasing demand and competition for water from other sectors within South Africa have caused that there are fewer opportunities to expand irrigated areas. The focus therefore needs to shift from investing in formal irrigation as the solution to new innovative ways of thinking to improve productivity of water, access to water by the poor and adopting an overall integrated, holistic approach to water resource management. The following water efficiency measures could be considered in the agricultural sector:

- Following the water balance approach to assess irrigation efficiency by applying a water balance to a specific situation rather than by calculating various performance indicators based on a once-off measurement of samples.
- Addressing wastage due to conveyance losses as well as the inefficient use of water in the sector can improve water efficiency within the sector by 30–40%.
- Improved irrigation practices with the implementation of sprinkler or micro irrigation.
  - Sprinkler irrigation can include centre pivot (LEPA), permanent sprinklers or flood piped supply irrigation efficiency of 95, 95, and 90%.
  - Micro irrigation should primarily include drip irrigation as it has an efficiency of 95%. Improved irrigation systems can contribute to water savings of 10%.
- Improved water control as well as land management and agronomic practices.
- Implementation of resource conserving agriculture.
- Removal of alien invasive plant species.
- Low cost technologies such as the harvesting of rain water and runoff as well as other basic measures.

Various strategies can be developed and implemented to improve water efficiency within the agricultural sector. Water management plans are required by the National Water Act for irrigation schemes which involve the establishment of current water use, setting of targets for improved water efficiency as well as planning for the realistic achievement of these targets. The DWS have made the enforcement of the principle of universal water measurement for irrigation a priority action. For water savings to be achieved, the DWS however needs to implement and enforce this in reality.

It is important for the sector to make large efforts in using water efficiently from water delivered to farm storage, distribution systems and in field applications through improved management practices. It should be highlighted that according to Reinders (2011) high irrigation uniformity was found to be of primary importance in terms of design and maintenance to improve crop yields as well as water efficiency. The employment of sufficient irrigation systems can improve water use efficiency on farms through drip irrigation or by making significant improvements in water use efficiency by managing and operating present schemes more effectively. Drip irrigation in terms of surface and subsurface application has an efficiency of 95% and high potential for water savings.

As indicated in Chap. 4, the largest potential for water savings can be achieved by addressing wastage due to conveyance losses as well as the inefficient use of water in this sector. Water Conservation and Water Demand Management (WC/WDM) should therefore be focussed upon decreasing seepage, percolation and degradation in quality of return flows. Wastage from stock-watering systems can also be included however it accounts for less than 1.5% of all water use in the country and more emphasis should be placed on irrigation. The second edition of the National Water Resources Strategy (NWRS) needs to focus on the development of a regulatory support and incentive framework to improve irrigation efficiency by aiming to influence optimal use of water within the commercial sector where water savings can be released to emerging farmers and provide user management of irrigation schemes. The state aims to reduce water losses by 30–40% within this sector with the application of specific strategic actions and guidelines (DWS 2004a, 2014; FAO 2012; Colvin 2015).

Improved water control as well as land management and agronomic practices should also be implemented to increase yield increases which will consequently make the agricultural sector less vulnerable to increased water stress in the country. These strategies can include improved soil fertility management and plant protection, choice of genetic material, possibly adopting plant breeding and biotechnology to increase harvestable parts of biomass, reduce biomass losses, reduce soil evaporation and ultimately reduce susceptibility to drought. The management of overall water demand by expanding the focus to water productivity and not just technical efficiency of water use can therefore promote water efficiency in the sector (DWS 2004a, 2014).

A regulatory support and incentive framework can also be adopted to improve water efficiency and productivity by promoting optimal use of water. This will enable water to be released for use by previously marginalised farmers and other sectors and be achieved through water allocation and compulsory licencing processes. Opportunities will in turn arise for new entrants to trade the water allocation with established farmers while established irrigators should implement water conservation measures. New entrants should however first develop appropriate and efficient irrigation infrastructure and practices before they can claim their water allocation (DWS 2004a, 2014).

Various technologies and techniques exist worldwide which can be adopted to increase water efficiency. African innovations and adaptations can however have greater effect on the continent or region than those transferred from elsewhere. Irrigation system innovations such as water harvesting, drip irrigation and conservation farming have proved to be somewhat successful. As indicated increased yield output from the same/less amount of water can ease strains of water scarcity and reduce additional storage need. This is achieved by alternative agronomic practices but also improved water application technologies and management practices. This approach is also called precision irrigation which is not always necessarily expensive "high-technology" but also includes a broad range of technologies and water management practices such as drum and drip irrigation, treadle pumps. These mentioned technologies enable farmers with limited access to water supply to water their crops with increased efficiency. Water efficiency of existing conventional technologies can also be improved upon with the adoption of proper irrigation timing instruments (DWS 2004a, 2014).

Innovative solutions should be adopted rather than believing that government investment in formal irrigation schemes is the solution. More effort should rather be required in the harvesting of rainwater, development of wetlands for agriculture, the use of shallow groundwater aquifers without undermining sustainability and the recycling of liquid and solid wastes and nutrients from urban areas i.e. water re-use or recycling. Consequently farmers should attempt to incorporate these mentioned water efficiency measures into their farming practices. This may however not be affordable for all. The government should therefore develop and implement subsidy programmes focussed upon marginalised farmers to assist them in adopting these measures as well as develop and implement incentive based regulatory system to promote the implementation of WC/WDM in the agricultural sector, especially in terms of commercial farming. These regulations should however be enforced by the relevant department to ensure compliance as well as improved WC/WDM in the agricultural sector as a whole.

Brown and Nooter (1992) states that small-scale farmer-controlled irrigation is still applicable and has been successful. Changes implemented for immediate results included fertiliser regulation and field modification as well as promotion of public health and conservation through educational programmes for communities to take ownership and responsibility to protect their water resources. The programme also called for the levelling of fields to eliminate irregular elevation to reduce constant flooding of the field as well as scheduling the watering of the field during the night to limit evaporation. Farmers were also encouraged to capture and reuse runoff water and line irrigation canals that deliver water to fields. By lining canals the efficiency already increased by 35% (Incencio et al. 2003).

A number of changes were implemented on a small community/individual farmer level within the Sahel as well as other African countries. Most effective measures included simple low cost technology, private individual operation system and sufficient infrastructural support to permit access to inputs and to markets to sell surplus production, high and timely cash returns to farmers and farmers were actively involved in the design and implementation of the project (Incencio et al. 2003).

Resource conserving agriculture which includes rainwater harvesting, conservation agriculture and integration of livestock and aquaculture into farming systems has led to an average crop yield increase of 79% and high water efficiency gains in developing countries. In situ soil and water conservation technologies can therefore improve water and nutrient management as shown in cases from eastern and southern Africa.

Ex situ water harvesting and storage have also proved to be a sufficient measure. These measures can include the following:

- Small storage dams which can be used for multiple purposes including livestock water and supply domestic water to villages and small towns;
- Rooftop rainwater harvesting and above ground storage tanks used to store water or with drip irrigation kits;
- Underground tanks to catch underground surface runoff as a cheaper alternative; and,
- Micro-systems which include micro-sprayers, mini sprinklers and drip irrigation systems. Drip irrigation systems which enable farmers to make use of limited water and fertiliser to grow high value crops. This system is viewed as the most water efficient type of irrigation.

Low cost technologies such as the harvesting of rain water and runoff as well as other basic measures can have a large scale impact on water efficiency and high level technologies are not always required.

Flood irrigation has also been researched in the Eastern Cape where soil crusting is typical. It was established that flood irrigation proved to have higher infiltration levels over the short and medium term in contrast to quick surface sealing which had low levels. Computerised irrigation systems obtained from Israel and were adapted and introduced by the Water Research Commission. A range of computer programmes are available for the design of efficient irrigation systems. Centre-pivot irrigation has also been introduced and the efficiency estimated at 80% (Incencio et al. 2003; Annandale et al. 2011; Reinders 2011).

The water balance approach has also proved to be an effective measure. The approach entails that irrigation efficiency be assessed by applying a water balance to a specific situation rather than by calculating various performance indicators based on a once-off measurement of samples. This approach calls for optimised irrigation water supply aimed at maximising yield and implies the efficient delivery of water from the source to the field (Incencio et al. 2003; Annandale et al. 2011; Reinders 2011).

Therefore the agricultural sector needs to undergo a mind shift whereby water is considered as both a scarce and valuable resource and agricultural input which should be used optimally for increased yield as well as sustainable current and future use. An incentive based system would be beneficial in terms of increasing the adoption of the mentioned water efficiency measures. The government should however provide the necessary guidelines and support (possible water efficiency subsidies) to the agricultural sector to ensure that WC/WDM is implemented. A mind shift can only be achieved if a necessary regulatory system is put in place by the relevant government department whereby water efficiency standards and regulations are enforced. There is therefore huge potential for consultation and collaboration between the agricultural sector and other businesses sectors for the investment in the development of innovative irrigation practices as well as appropriate methods to increase current crop yields to make this sector more water efficient.

8.2.2 *Industry, Mining and Energy Sector*

As indicated in previous chapters, industries, mining and energy sectors are not homogenous due to varied water use and universal water efficiency targets cannot be set across the board. Significant variations in the balance of water demand and supply exist in South Africa and basins which are characterised by industrial centres have the largest gaps. The Waterberg in the Limpopo province can be used as an example. This region holds 40% of South Africa's coal resources however insufficient water have proved to be the biggest constraint for the mining of these resources. Catchments like these needs protection to avoid having to deal with stranded assets in the future. It is also estimated that the Upper Vaal WMA, where 44% of water demand is attributed to industry, will experience a 33% exceed in supply in 2030, while the Olifants catchment (near Johannesburg) will experience a gap of 39% demand (DWS 2011; CDP 2012).

Presently very few companies have measurable water use targets and there is a huge variability in the nature and ambition of targets as well which points to a lack of urgency in terms of water related targets. Very few quantifiable targets exists and most of these are intensity targets which range from 0% ambition (retaining water intensity at its current level) to a 30% reduction in water intensity. Even though concerns have been reported by companies regarding water quality within the country, very few have set targets relating to water quality. Other targets such as commitments to improve water accounting, reduce freshwater intensity and to improve the ratio of water recycled to high quality water consumed have also been adopted by few and differ in ambition. Companies therefore primarily see opportunities to mitigate risk (value protection) rather than new business opportunities (value creation) even though most have reported that there is water related opportunities with potential to generate substantive changes in business. The primary opportunity identified was cost savings in the form of water efficiency and recycling measures, followed by reputational benefits. Very few reported opportunities relating to the sales of new products and technologies which address water related challenges (ICMM 2012; DWS 2014).

The meeting of water demand of power generation will also be a significant challenge. Much of the additional power capacity will come from coal however; water supply has proved to be insufficient for both coal mining and power generation. Eskom have been using "wet-cooled" technology where a typical large power station requires 45 million m^3 per annum of water. Due to water supply problems, the technique has shifted to "dry-cooled" systems which use 6 million m^3 per annum of water for a similar size power station. Dry-cooled power stations cost more to build and operate and is less efficient than wet-cooled systems. However due to increasing water pressure this change was a necessity. Renewable energy should also be placed at the forefront to meet future energy demand due to it having a very low water demand which can create water savings to be invested in other sectors or avenues (ICMM 2012; CDP 2012).

In terms of hydropower stations, the country does not have adequate water supplies to meet the required need of large stations. Small hydropower generators are a possibility in few cases with the key being that it is used in conjunction with irrigation or other storage releases. In terms of the country's fuel requirements, Sasol has become a significant supplier and the water requirement to build another Coal-to-Liquid (CTL) plant has received priority. The production of biofuel crops for biodiesel or ethanol may have significant implications for water availability and needs to be reconsidered as water will need to be supplied to the processing plants as well as have a large feedstock requirement if crops are irrigated (ICMM 2012; CDP 2012). This needs to be taken into account and focus should rather be placed on other types of renewable energy sources with a lower water demand.

As described in previous chapters, the use of water in mining operations affects water availability in terms of availability as well as quality due to the risk of pollution from disposed waste water. In order to address the lack of water efficiency in terms of pollution, mining companies will have to invest in measures to ensure that water does not get contaminated or where contamination has occurred that they invest in treatment or containment within the relevant reservoirs, pipelines, canals and other storage facilities. Planned water discharges into receiving environments need to be monitored very carefully and needs to be controlled to ensure compliance with regulations to minimise the impact on receiving waters. The discharge of treated process water needs to be routinely monitored and must meet specific standard and requirements in terms of relevant water quality parameters such as pH, conductivity and temperature. Other discharges which occur from regular runoff, extreme storm events and discharge from surplus dewatering need to be contained and discharged appropriately (ICMM 2012; CDP 2012). These measures may prove to be of high cost to companies however these measures need to be implemented by these companies and enforced by relevant authorities to ensure the minimisation of water degradation within affected environments to improve overall water efficiency within the mining sector.

Leading companies in the mining sector have anticipated the trend of water demand exceeding availability as well as the accompanied impact on the quality of existing water resources and have invested in large body of research to inform their pragmatic responses. These responses have included improved performance in water management through increased efficiency, technological innovations and sharing of good practice. It has therefore become vital that a continued effective engagement exists between industries and other sectors on sustainable water management as well as that there is an understanding of the value of water to all users and the environment.

It is expected that mining companies as well as industries will be increasingly affected by the way in which they respond to water related problems by issues such as water accounting, value of water, technological innovations and stakeholder engagement. Water accounting will have to be used by companies to understand the company's needs as well as its water footprint in terms of quantity and quality. A good example of the successful use of water balancing is the Water Working Group of the Minerals Council of Australia. Australia has many areas prone to significant water stress. The mentioned company worked in collaboration with the University of Queensland's Sustainable Minerals Institute to develop a single set of water metrics for the Australian mining industry to enable consistent reporting, benchmarking and the identification of opportunities to improve water management. Mining as well as industries can therefore use this as an example to establish their own water balance through collaborations to improve overall water management and promote water efficiency within these sectors (ICMM 2012; DWS 2011; CDP 2012).

The value of water will also be influenced by factors such as pricing policies, water treatment costs and the social and environmental value which will be placed on water. The increasing interest in the ecosystem services approach have highlighted the relationships which exists between industrial/mining activities and the provisioning services of the environment such as water on which ecosystems depend. The monetary value of water will continue to rise and will therefore become a growing consideration in financial planning as well as feasibility studies of mining operations (CDP 2012; DWS 2014).

In terms of technological innovations, these will continue to be developed in an attempt to find cost effective and innovative solutions to address the challenges accompanied with obtaining water, reducing water demand of mining processes and designing more efficient and effective means of water management and treatment and is therefore a huge investment opportunity for business sectors or for companies to become involved. Many large companies have become committed to technological research, innovation and development to assist business efficiency and good water practice. Technological innovations should therefore be invested in by industrial and mining companies to find more innovative and cost efficient ways to increase water efficiency in their operations. This can in turn be beneficial towards the company in terms of reputational value but also reduce financial losses from water wastage or inefficient practices (ICMM 2012; CDP 2012; DWS 2014).

Increased stakeholder engagement will also become an increasing factor for industries and mining companies and can be beneficial to water efficiency. Companies should therefore incorporate this into their strategic planning to ensure that they are able to contribute to debates on water issues by staying up to date with current water related issues. Stakeholder engagement through constructive dialogue with others on responsible water management will enable them to learn from other perspectives and to contribute to the debate. Stakeholder engagement is essential to reach consensus and agreement on water issues that affect the mining operations as well as the communities in which it operates. This type of engagement will provide a means for the sector to contribute to debate on developing regulations and standards and provides them with the information needed to operate in ways which are consistent with the basic human right to having access to clean water. Engagement needs to occur on a global, regional and operational level to ensure that there is a consistent and constructive voice in the emerging policy debate (ICMM 2012; CDP 2012; DWS 2014).

The abovementioned factors should therefore be incorporated into industrial and mining operations to promote the implementation of effective water management practices within their operations but also benefit these in the form of reducing financial losses incurred by inefficient practices and water wastage.

Another tool which can be used by industries as well as mining companies to reduce their water usage is the implementation of the "Water Footprint Network" assessment method. The water footprint method was primarily used to calculate the general water use for countries however it was recently applied by Haggard et al. (2014) on two concentrator plants with good results. This tool therefore holds significant potential in reducing companies' water use by assisting industries and mining companies to first understand how water is used within its operations, from where it sources water, how much it uses and what return flows are and the quality thereof. Few companies have implemented this method and there is therefore a huge potential for water savings if this method is implemented by most industries and mining operations in the country. The obtained information can also be benchmarked against other processes (similar or dissimilar) to compare its water use and to ultimately assist in the understanding of if the operation is using water as a resource efficiently through calculating a water account for the process (ICMM 2012; CDP 2012; DWS 2014).

The water footprint tool is an effective tool in determining the volume of direct and indirect water utilised by an organisation in a process or to manufacture a product. The gathered information can consequently be used to assess the impact on the local environment and to identify strategies to reduce water requirements to ultimately determine the impact of operations on ground and surface water resources (Hoekstra et al. 2011). The information can be used by policy makers, business leaders and regulators to develop new or revised water use and management strategies (Haggard et al. 2014).

There is therefore an opportunity for consultation and collaboration between government and the relevant stakeholders for the development and implementation of regulations which oblige industries and mining operations etc. to make use of the water footprint tool. This will in turn develop a necessary database of water usage within the industrial, mining and energy sector for the country but also assist in companies to reduce their water wastage to consequently reduce financial losses related to water wastage. Therefore there is a huge potential for such initiatives to develop this method into an effective measure to increase water efficiency by companies reducing their water footprint but also assist companies to reduce financial losses related to possible ineffective processes and/or water losses/wastage.

Practical measures which could be implemented for WC/WDM can include the "Water for Growth and Development Framework", non-potable use of partially treated effluent, improved efficiency of effluent treatment plants with the implementation of reverse osmosis technologies as well as the installation of new technologies or retrofitting. The recycling of process as well as decant water through treatment for supply to other mines or industrial users as well as municipalities can also be incorporated as a water efficiency measure (ICMM 2012; DWS 2014).

Even though the majority of companies within these sectors in South Africa have a lack of urgency related to water efficiency, some large companies have taken up the challenge. Some cases of leading practice in improved water efficiency include the following.

Anglo American have started to work on adaptations to climate change and have initiated a "Rain Immunisation Project" which seeks to decrease environmental risks and production time loss at sites in Australia caused by high variability in precipitation. The project is constituted of extensive pump and piping networks, improved flood protection infrastructure, road crossings and road-sheeting on semi permanent roads, upgrades to underground mines, drainage network, storage and dewatering capacity. This project has consequently provided the basis for detailed wet weather plans at each operation which also takes into account possible drought scenarios (CDP 2012).

Anglo American Platinum with the collaboration of the municipality in the Rustenburg area has decreased its water usage to manage the increased demand for potable water. The company signed an off-take agreement to use 15 mL per day of treated sewage water effluent from the municipality's sewage treatment plant and commissioned a R15 million water treatment plant at their Rustenburg operations in November 2011 in an attempt to improve water quality of treated sewage water introduced into the water reticulation system. The project therefore focused upon substituting treated sewage water for potable water and the collaboration have resulted in the conservation of significant amounts of potable water (CDP 2012).

Other case studies include Gold Fields, gold mining company, where 90% of withdrawn water is recycled and reused. Exxaro Resources have also been involved in public policy, engaging with government on integrated water licences and have supported academic and business co-operatives in the form of sponsoring environmental chairs at South African universities to encourage research and dialogue. Mondi Plc, an international packaging and paper Group with operations across more than 30 countries, is also sponsoring projects such as the "Mondi Wetland Project" and the "Mondi Ecological Network Programme" which have become leading developments in wetland conservation and ecological networks. Mondi has invested huge amounts of money on a number of efforts to protect biodiversity through identifying and protecting areas of high conservation value, and developing best practice plantations through its New Generation Plantation projects with World Wildlife Fund (CDP 2012).

Lastly, Sasol has settled a three multi-stakeholder partnership agreement in an attempt to assist in the reduction of physical losses in catchment areas within which its main operations are located. The company has developed water conservation partnerships with local municipalities as well as supporting a programme which focuses on the repair of household water leaks and leakages from distribution pipelines. Sasol has invested R8 million in these partnerships with a committed leveraged partner funding of R9 million. These partnership projects will be used as case studies to develop a national water-offsetting model in collaboration with the DWS (CDP 2012).

Therefore, industry, mining and the energy sector can make strategic changes in their operations to reduce current water use, adopt and implement technological innovations as well as invest in the development of partnerships and programmes to increase water efficiency. These water efficiency measures can be of high cost however the mentioned case studies have illustrated that companies can benefit through reducing their risks of water related issues such as drought but also lead to reputational benefits. More importantly, the implementation of the above mentioned water efficiency recommendations could reduce financial losses incurred from inefficient practices or methods as well as from water wastage, leading to more economic gains in the future.

8.2.3 Domestic/Municipal Sector

Multiple water management area assessments and reconciliation studies have been conducted in an attempt to investigate the potential to reduce water demand by local government through the setting of targets to reduce water demand. The government has also set a target to reduce water losses of 39% by half. It has been stated that municipalities should rather initiate measures to reduce their water losses rather than continue with target setting as this has had minimal impact and shown little benefit.

The government has therefore called for the implementation of WC/WDM measures to reduce water losses and NRW and municipalities are required to submit quarterly reports on their activities and the reduction of their water losses and NRW in terms of an outcome based performance management system. The following measures have been recommended for municipalities to address their water losses and NRW.

Focus needs to be placed first and foremost on the reduction of leaks in reticulation networks and distribution leaks. It is estimated that this can reduce unaccounted water to 11% and a saving of 15% of the total demand. Adequate technically correct operating and maintenance measures need to be in place in the reticulation network system. Municipalities should also undertake the replacement or rehabilitation of the pipe network and an accepted general norm should be incorporated whereby reticulation networks should be replaced every 50 years (can vary with circumstances). Distribution leaks can also be reduced by municipalities through leak detection and repair, pressure management, effective zoning of the distribution system, repair of visible and reported leaks, pipe replacement or management programme, cathodic protection of pipelines, meter management programme as well as unauthorised connection programme (DWS 2004b).

A programme should also be implemented to reduce plumbing leaks in households. It is estimated that 20% of total indoor water use is wasted through plumbing leaks which include any leaks on the consumer side of the connection, leaks within the connection pipe, leaking taps, leaking toilets and leaking hot water geysers

(DWS 2004b). The repair of plumbing leaks can be achieved by the following activities initiated by water service institutions:

- Leak repair projects in the former urban black townships sponsored by water institutions (re-addressing the apartheid plumbing of council houses);
- Communication and educations campaigns; and
- Ensuring payment of services through credit control measures.

The majority of DWS budget (76%) went into water infrastructure and development. The government has also consequently implemented the "war on leaks" project on 28 August 2015 where DWS will train 15,000 artisans and/or plumbers to fix leaking taps and pipes in their communities as part of promoting water conservation. Rand Water has been given the task to implement the project which will run over a number of years whereby the 15,000 unemployed youth will be trained within three disciplines namely water agents, artisans and plumbers consequently ensuring that the country's water sector is equipped with competent artisanal skills and capacity to minimise water losses (RSA 2015). Leaks should also be reported by the community to their relevant water service provider to ensure that leaks are addressed as soon as possible to reduce water loss.

It is also recommended that municipalities retrofit existing plumbing fittings with more efficient ones and can consequently reduce household and commercial water consumption by an estimated 40%. Retrofitting opportunities include fitting dual-flush or interruptible toilets, user-activated urinals, low flow shower heads and tap controllers and aerators (DWS 2004b). The government's solar water geyser subsidy system has proved to be a successful measure and is now under the Department of Energy with rebates of thousands of rand offered to consumers who install the systems. The following activities can be undertaken by water service institutions in terms of retrofitting:

- Retrofit projects in the "former urban black townships" sponsored by the water institutions (combined with leak repair projects described above);
- Communication and education programmes;
- Grant incentive schemes where water institutions pay the consumer part for retrofitting costs;
- Regulations and by-laws;
- Marketing and research of new technologies; and
- School audits

Reduction in gardening water use has also been placed as a measure which municipalities should focus on. It is estimated that total consumption can be reduced from 6 to 30% by increasing efficiency of gardening water use. Opportunities to reduce gardening water use include water-wise plants, mulching, efficient irrigation systems, irrigation scheduling, rainwater harvesting and recycling of waste water (DWS 2004b). The following guidelines have once again been set for municipalities or water service institutions to reduce gardening water use:

- Communication and education campaigns which include water wise demonstrations exhibits;
- Implementation of block rate tariffs;
- Regulations and by-laws;
- Research of new technologies such as linking soil moisture monitors to automatic garden irrigation systems; and
- Grant incentive schemes for lawn replacement and zero-scaping where water institutions pay a part of the costs to change existing gardens

Lastly, municipalities should also reduce the demand by new consumers through selecting appropriate levels of service for different communities, efficient plumbing fittings, efficient reticulation design practices and pre-payment meters (DWS 2004b). The following guidelines have once again been set for municipalities or water service institutions to reduce new consumer demand:

- Installation of pre-payment systems if it is economically, technically and socially viable;
- Communication and education campaigns;
- Regulation and by-laws;
- Negotiations and incentives to developers;
- Improved reticulation design and plumbing standards; and
- High level operation and maintenance with rapid response rate to bursts and leaks.

Successful pre-payment system has been implemented by Johannesburg Water in Soweto whereby residents are given the opportunity to install a prepaid water meter by Joburg Water. This door-to-door project has achieved significant water decrease per property from over 50 kL per household per month to less than 12 kL per household per month through the implementation of the pre-payment for water project. The pilot project showed an 80% saving of the water typically consumed under "uncontrolled" conditions which have led to both water savings as well as a decrease in financial losses (Singh and Xaba 2008).

Multiple guidelines have been set out by the DWS' NWRS second edition to achieve a reduction of water losses in the country and to promote WC/WDM. Attempts have usually been focussed on narrow technical solutions however the new strategy has incorporated communication and education campaigns in an attempt to raise awareness together with the implementation of technical solutions. It should be noted that raising awareness should be approached in a strategic manner in order to change mindsets and behaviour of both the water users and managers. More importantly, raising awareness should be one of the first steps taken to achieve the acceptability and buy-in necessary for more technical measures to succeed. These campaigns should target all stakeholders including water services institution and local government and not just water users and consumers to facilitate changes in behaviour as knowledge increases.

Possible policy changes which could be looked at to promote behavioural change in terms of water use include grants for using more water efficient technologies, improved water efficiency labelling and domestic water charging on a flat rate, metered basis or block tariffs. Progressively higher water prices based on taxes have also proved to be effective in helping reduce consumption as well as initiatives focussed on community-based social marketing and technologies to monitor water use. Improved water efficiency labelling on products could also promote behavioural change through indicating the amount of water needed to produce a certain product (Davies et al. 2014). Progressively higher water prices and taxation based on degree of water inefficiency or losses as well as the implementation of tax breaks for the purchasing of water efficient products and technologies could also be implemented to promote the adaptation of WC/WDM practices (Davies et al. 2014).

The recent drought within South Africa (worst drought in three decades) has called for a change in behaviour towards water use and has raised awareness regarding the country's current water availability and quality. However very few municipalities or water service institutions have adopted or implemented these programmes and schemes. The consumer is still mostly responsible for the plumbing cost to reduce household leaks and will have to invest in water efficient measures themselves as there is a lack of grant incentive schemes.

Water efficiency in households can be increased by introducing water saving behaviours with the instalment of water efficient technologies and products. It is recommended that households first complete a water audit to assist in prioritising areas on the property which use the most water. The targeting of these priority areas will lead to the achievement of bigger savings and quicker results.

Typical water use for a middle income four person household with garden includes 25% garden and outdoor, 25% toilet, 24% bath and shower, 13% laundry, 11% kitchen and 2% other. Therefore in terms of this domestic example, most water savings can be achieved by focussing on water efficient technologies for bath and shower, toilet and garden and outdoor. Typical water use for a commercial property (hotel with 300 rooms with no irrigation) includes 37% guestrooms, 21% kitchen, 17% public toilets, 12% laundry, 6% coldrooms, 2% pool and 5% other. Therefore most water savings can be achieved with the implementation of water efficient technologies relevant to guestrooms, public toilets, the kitchen and laundry. Lastly, the typical water use for institutional properties such as a highschool (1200 learners with sportsfield) includes 48% toilets, 38% irrigation, 6% swimming pool, 1% classrooms and 7% other. Most water savings can be achieved with the instalment of water efficient technologies relevant toilets, irrigation and the swimming pool (Jacobs 2008; Price 2010).

Levels of water losses in South Africa varies across the different municipal categories. As indicated in Table 8.1, mostly rural areas account for the most of NRW while metros and secondary cities have the highest water use per capita. For the country to achieve water savings, NRW needs to be addressed through the previously discussed measures as well as the implementation of more water efficient practices to reduce overall consumption per capita. Water loss as well as high water consumption behaviours therefore need to be addressed in unison to ensure effective water savings.

Table 8.1 Levels of water losses in South Africa (Water 2014)

Municipal category	Water loss (%)	Litres/capita/day
A (Metros)	29.2	280
B1(Secondary cities)	38.5	249
B2 (Large towns)	38.3	204
B3 (Small towns)	36.2	174
B4 (Mostly rural)	58	164
Total for 2011/2012	**37.2**	**226**

Table 8.2 Low cost interventions for improved water efficiency for domestic, commercial and institutional properties (Price 2010)

Low cost intervention			
	Technology options	Water saving action	Cost
Taps (baths, bathroom basins, kitchen basins and gardens)	• Flow regulator: provides water at prescribed flow rate independent of pressure • Thermostatically controlled mixer taps: ensure required amount of hot water is used • Tap aerator • Push button (self closing) taps for high use areas: ensures that taps close automatically after use • Insulation of geyser and water pipes: less water wasted by waiting for hot water	• Repair dripping taps • Turn off the tap while brushing teeth • Wash vegetables in a bowl and not under running water • Do not use hot water to defrost food	Standard tap: R105–800 and uses 15 L per minute **Low flow aerated tap**: R220 and uses 6 L per minute **Savings: 60% of water (average size four person household)**
Shower	• Flow regulator: restrict flow through standard showerhead • Temporary shut off valve: allows user to temporarily shut off water while washing and maintains desired temperature setting • Metered shower systems: shut off after a predetermined volume of water has been discharged • Pressure control valve: ensure hot and cold water are balanced	• Shower in stead of bathing (66% saving) • Reduce time in the shower (5 min) • Turn off shower while applying soap or shampoo	Standard showerhead: R90–1000 uses 20 L per minute **Efficient Showerhead**: R400–1000 uses 7 L per minute **Savings: 65% (average size four person household)**

Various water efficiency technologies and products exist with varying costs. Low cost interventions relevant to domestic, commercial and institutional properties can include the following as indicated in Table 8.2.

Other water saving actions which can be implemented to decrease water loss from the swimming pool and water features can include to keep swimming pools covered when not in use to reduce evaporation, not over-filling the pool to reduce

Table 8.3 Medium cost interventions for improved water efficiency for domestic, commercial and institutional properties (Price 2010)

Medium cost intervention			
	Technology options	Water saving action	Cost
Toilets	• Install a cistern displacement device in older 10–13 L cisterns: reduces water used per flush • Convert to single flush toilet • Install a leak free toiler cistern: does not fill until flush button is pressed • Interruptible flush mechanism: flush only the required amount of water • Install waterless toilet system: composting toilets and waterless urinals	• Do not use toilet to dispose of rubbish • Do not dispose unwanted medicine and chemicals	Standard toilet: R1500 and uses 11 L per flush **Dual flush toilet**: R1500 and uses 6/3 L per flush **Savings: 65% of water (average size four person household)** Standard urinal Flush valve: R550–900 and uses 2.2 L per flush **Water efficient flush valve**: R800 using 1.5 L per flush **Savings: 32% of water (average size four person household)**
Baths	• Install shower or bath/shower combination with water efficient showerhead to encourage showering • Install smaller bath • Insulate geyser and water pipes	• Do not put more water in bath than necessary • Share bath water • Reduce time taken to bath to reduce additional hot water required • Shower instead of bathing	**Savings**: 65% (average size four person household)

splash out, avoiding excessive backwashing, checking pool leaks, design pools to have a small surface area to volume ratio to limit evaporation and lastly design water features so that gutter water or runoff from clean paved areas flows into the pond. Medium cost interventions relevant to domestic, commercial and institutional properties can include the following as indicated in Table 8.3.

Currently, 91% of the country's population has access to sanitation services. The adoption of services such as dry sanitation may be required if sustainability, affordability and some level of growth to benefit society, are to be achieved in areas of extreme water scarcity. For example, in some Northern Cape towns there is not enough water to provide for water borne sewage and to serve the mines upon which jobs and the local economy are dependent. The region has therefore started with the implementation of dry sanitation to reduce water demand in households as well as address the sewage treatment problem.

Average washing machines use 11 L of water for every kilogram of cotton and dishwashers between 10 and 21 L. In terms of washing machines and dishwashers, good water saving actions can be implemented. Washing machines should be used only when it is fully loaded and hot water should only be used when required. Dishwashers should also only be used when it is fully loaded, excess food should be scraped off in stead of rinsing them and a time based sensor can be installed to shut industrial dishwashers down when not in use. More efficient cleaning products such as washing powders can also be adopted to decrease the amount of water needed for laundry activities. The installation of more water efficient washing machines and practices can reduce water use to 9.3 L of water for every kilogram of cotton and in terms of dishwashing machines 7–17 L on an energy saving program.

Medium to high cost interventions can be implemented for outdoors or gardens and include grey water recycling and rainwater harvesting. Good water savings actions for outdoor or gardens include using a broom and not a hose pipe to clean paved areas, irrigate early morning or late evening to limit evaporation, irrigate less frequently but for a longer period to reduce wastage through evaporation, ensure irrigation systems are correctly installed, plant indigenous plants, use a trigger gun on a hose pipe to control flow and avoid excessive amounts of fertiliser on the lawn as it increases the need for water (Jacobs 2008; Price 2010). The installation of water efficient irrigation systems as well as the introduction of greywater recycling and rainwater harvesting can reduce water losses by a minimum of 50% in gardens (US EPA 2016).

Grey water recycling which refers to the re-use of waste water can also be implemented. Water from hand basins, showers and baths can be used for other functions that do not require drinking quality such as flushing toilets and watering of gardens. Basic systems such as grey water irrigation systems can be installed. These systems typically cost R1000–R4500 but will pay themselves back in 1–2 years. Advanced recycling units can be installed for specific requirements and can recycle up to 10,000 L per day. These systems include filtration, sediment disposal, biological cleaning and UV disinfecting facilities and can cost up to R45,000 (Price 2010).

Lastly, the implementation of rainwater harvesting has a significant potential for water efficiency. Typically rainwater is collected from roofs or paved areas of residential, commercial and industrial properties and can be used for toilet flushing, laundry and irrigation of gardens. Rainwater harvesting can also reduce stormwater flow. Simple low cost interventions can also be implemented such as diverting water from down-pipes to irrigate gardens or fill pools and water features (Jacobs 2008; Price 2010).

A case study of successful implementation of rainwater harvesting can be found in a study which was conducted in Kleinmond, Western Cape. Domestic rainwater harvesting systems were used in conjunction with the municipal water distribution system. O'Brian (2014) concluded that rainwater harvesting can be used as a principle or additional source of potable water in some cases or can be used as a supplementary source of non-potable water for laundry, garden irrigation, cleaning and toilet flushing. Depending on normal household usage, rainwater harvesting practices can save 30–50% of treated drinking water from the mains in houses and up to 80% of the treated drinking water in a business or commercial building. The amount of rainwater collected will depend on the size tank installed. On average, 100,000 L per household are commonly quoted and much more for a large roofed commercial building. Rainwater harvesting is currently the most widespread water resource management strategy in South Africa, however the tool has not yet advanced far enough towards its full potential due to it still only being an alternative water use for selective domestic end-uses. The lack of use within urban areas is attributed to its high cost of installation and due to the tanks being aesthetically unappealing (O'Brian 2014).

In comparison to urban areas, rural areas have embraced the feature as it is a reliable water source and in some cases acts as the primary source of drinking water. The benefits of rainwater harvesting in rural areas far outweigh the cost and government have consequently developed an incentive for rainwater harvesting to reduce the system demand. Rainwater harvesting is capable of supplying at least 50% of the allocated system demand provided it is used for appropriate end-uses such as flushing of toilets. Rainwater harvesting have also reduced stormwater discharge and could meet 62% of household's irrigation requirements. Therefore with the assistance of government incentives, rainwater harvesting has become a key source of water within rural communities and has subsequently decreased pressure on the relevant water systems (O'Brian 2014).

In conclusion, the adoption and implementation of WC/WDM measures may in some cases be of high costs however are often less than maintenance costs which are often ignored and consequently leads to the measures failing within a year or two after being implemented. A range of potential water savings can be achieved in this sector with the implementation of appropriate measures. It is however imperative that the attitude and behaviours toward water resources be changed through the realisation that South Africa is a water scarce country where WC/WDM needs to form the core of all planning and strategic actions in all sectors. Sectors should therefore focus on cost-effective and affordable water efficiency measures or products, revise their consumer choices by considering the amount of water embedded in the production of products such as meat, softdrinks and other daily used products and adopt behavioural changes such as showering instead of bathing to decrease their water use. WC/WDM can be effective and sustainable if the necessary buy-in is achieved from various stakeholders and can be an immediate and long term incentive for households in terms of possible water savings.

8.3 Strategic Actions

The development of water resource infrastructure will have to be implemented in the context of water conservation and water demand management through the establishment of a protocol within the NWRS. This protocol calls for water efficient use as a priority and for future infrastructure to be developed in the alignment of water efficiency. Reconciliation Strategy studies contain efficiency targets to boost a balance in water supply and demand through providing structure and guidance for planning processes. Key areas that provide water efficiency prospects are based on effective measurement and management of water use (DWS 2014). The key question is however how this and the possible water savings can become a reality.

As indicated, the DWS have identified specific strategic actions to promote the achievement of water conservation and demand water management for the country to address its current water loss in the different sectors and to start adopting and implementing water efficiency measures. These strategic actions include the following and should be noted when deciding on adopting and implementing water efficiency measures within the different sectors.

For water efficiency to materialise, all sectors need to ensure that the relevant and practical interventions are implemented. The DWS and WRC have consequently developed the following guidelines for municipalities to achieve this. These guidelines will have to be used to support the implementation of measures and will have to be monitored through authorisation conditions (DWS 2014).

In order to entrench water conservation and water demand management in South Africa, water allocation and water use authorisation will have to be implemented and monitored. Water scarcity needs to be placed at the forefront in all sectors when considering water use authorisation and water use applications need to include water conservation and water demand management measures where the extent of water use efficiency is outlined. Water efficiency should therefore be the key consideration in the allocation of water use.

Water efficiency will have to be monitored through authorisation conditions and the country will consequently have to strengthen the compliance monitoring and enforcement through incorporating water conservation and water demand management in the National Water Act over the next number of years. This will give water efficiency enhanced attention and hopefully ensure implementation. Measures will have to be developed and compliance will have to be monitored and enforced by the DWS for water users to follow a path of continuous improvement. It is envisaged that all sectors (agricultural irrigation schemes, local government, industries, mining operations and power generation) monitor and regularly report on water loss and efficiency improvements such as water balances and water efficiency measures (DWS 2014).

The high percentage of NRW has placed growing concern on the lack of action by municipalities to attend to high water consumption attributed to water leaks especially in rural areas. Focus will also be placed on the repair of leaks by repairing plumbing leaks in the domestic sphere to reduce consumer consumption from 200–300 m^3 per month to 10–15 m^3 per month (occupancy dependent). It is therefore required for municipalities to be the main driving force in the reduction of household leaks within their WC/WDM programmes.

The DWS will also need to develop institutional capacity within its department to manage and regulate WC/WDM effectively. This can be achieved by placing WC/WDM as a priority within the National Water Policy Framework and the National Development Plan. Leadership and guidance will consequently be required from the DWS, the Department of Cooperative Governance and the South African Local Government Association for each sector. Once again the DWS will be expected to provide oversight and monitoring to ensure effective

WC/WDM measures across all sectors. National and regional offices will have to be appropriately structured and capacitated (DWS 2014).

WC/WDM will also have to be promoted through education and awareness campaigns or programmes as these are important mechanisms to bring need for WC/WDM to the public. This will hopefully trigger committed public actions and response through social awareness and is essential for balanced and sustained water use in the country. Engagement with the public and stakeholders can occur through media and other mediums to highlight the importance of water efficiency, to ensure that relevant information is shared and that the public is educated. This will consequently heighten the WC/WDM profile and hopefully achieve involvement and accountability from citizens. National Government as well as all sector institutions, private sector organisations and civil society should promote WC/WDM (DWS 2014). However, education and awareness campaigns have not achieved the necessary behavioural change in terms of water use and other measures as mentioned in this chapter should be considered and implemented.

Lastly, training and capacity building will have to take place to ensure sustainability. Training and capacity building will have to be a strong enabler for water efficiency measures and needs to be a systematic and long term initiative. This will enable users and regulatory institutions to work on their water resource management competence which should include WC/WDM through a variety of interventions.

There are therefore multiple possibilities in terms of water efficiency measures which can be implemented at varying degrees within the different sectors to achieve water savings through WC/WDM. The implementation of cost-effective measures will attribute to a significant source of savings and will consequently be accompanied with more productive water usage and increased energy efficiency across all sectors. The selection and implementation of these measures need to be localised to be able to provide the required specific economic and social needs of each particular region and sector.

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Part IV
Challenges, Recommendations and Conclusions

Chapter 9
Challenges and Policy Recommendations

The current challenges which face the water sector of South Africa need to be kept in mind when deciding on and implementing water efficiency measures within the various sectors. The most profound challenge facing South Africa is poverty. High poverty levels is exacerbated by high level of inequality and lack of access to natural, political and financial resources and is consequently one of the root challenges facing the water sector. Different constraints also exist in the variety of sectors of South Africa which may inhibit the adoption and implementation of WC/WDM solutions and measures. The implementation of management information systems as well as the other identified constraints needs to be kept in mind and be properly addressed for WC/WDM to be effectively implemented. Focus is placed on current challenges and constraints facing the implementation of WC/WDM as well as possible policy recommendations. There are multiple opportunities for businesses in the form of investments as well as the establishment of collaborations with various stakeholders in terms of water efficiency in the country.

9.1 Introduction

The current challenges which face the water sector of South Africa need to be kept in mind when deciding on and implementing water efficiency measures within the various sectors. This chapter will focus briefly on the possible challenges and constraints which the country's water sector might face in trying to realize efficient WC/WDM across all sectors. These challenges and constraints need to be kept in mind to ensure that appropriate cost effective decisions are made in an attempt to attain water savings within the country and promote effective WC/WDM. This will be followed by possible policy recommendations.

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_9

9.2 Overview of Challenges and Possible Constraints

The water sector of South Africa is first and foremost faced with the eradication of poverty. This is the most profound challenge facing South Africa. High poverty levels is exacerbated by high level of inequality and lack of access to natural, political and financial resources and is consequently one of the root challenges facing the water sector. Poverty manifests itself into the water sector in the inability to pay for water services and is therefore directly relevant to water resource management and needs to be taken into account.

Access to water is also a problematic factor which can make the development of water management as a tool a bit problematic. Water management tools therefore need to be developed in such a way that it permits the building of a socially and environmentally just society. While water efficiency has been acknowledged, economic development might play a damaging role with increased industrialisation, intense agriculture and more jobs placing more pressure on already limited water resources. Furthermore, for water demand management to be successful viable alternatives need to be developed and there needs to be a social willingness and ability to accept the technically generated solutions as being reasonable and legitimate. The allocation of water is also a challenge as there are few specific guidelines which determine this. The continued degradation of water quality also needs to be taken into account as it has an impact on the allocation of water. Lower water quality will lead to industries using greater amounts to compensate. The lack of positive behavioural change in terms of water use and conservation will perpetuate the grab for resources and may consequently lead to socio-economic unrest problems. Public participation process should also be implemented to avoid social instability due to increased water scarcity and technological solutions and options needs to be communicated to the people who they may affect (DWS 2014).

Different constraints also exist in the variety of sectors of South Africa which may inhibit the adoption and implementation of WC/WDM solutions and measures. These may include the following:

- *Financial constraints:* The implementation of water efficiency measures will require the investment of new technologies such as new irrigation systems which may not be readily available for farmers. Even though these strategies will be accompanied with economic benefits that can easily be justified, water service institutions are often financially constrained and may not have the adequate financial resources to invest in these measures. For example, low cost housing projects resort to the cheapest fitting for toilets and taps without taking the operating and running costs into account.
- *Planning constraints:* Current water resources planning practices in the variety of sectors are primarily focussed upon supply-side management and only consider infrastructure development as an option and not water efficiency measures.
- *Institutional constraints:* There is a lack of coordination among the various role players in the water supply chain (DWS, bulk water suppliers and local authorities) during planning processes. There has also been inadequate clarity on

institutional arrangements, roles and responsibilities. The agricultural sector is a good example of this constraint as most water users in this sector are in a transition phase whereby they are transforming from former Irrigation Boards, while new water users are learning the challenges of operating schemes.

- *Capacity constraints:* There is limited capacity available to plan, implement and maintain WC/WDM measures. This is specially the case in the agricultural sector. There are also capacity constraints in terms of limited technical and managerial capacity when attempting to plan, implement and maintain WC/WDM measures.
- *Technical constraints:* A lack of appropriate WC/WDM planning tools and guidelines exist in all sectors. There are no adequate standards and enforcement for irrigation techniques as well as other things such as plumbing products. When available these products are neither supported nor used as there is no incentive to do so.
- *Social constraints:* Most sectors perceive WC/WDM to be a non priority as it is only enforced during drought periods. It is perceived to be a drought relief mechanism. In certain areas there is also a low level of payment for services. Water wastage is mostly attributed to a lack of awareness of the benefits of water conservation and demand management. There is therefore mainly a lack of understanding of the value of water and that of WC/WDM (DWS 2014).

The above-mentioned are the main constraints across the different sectors with South Africa. Other constraints include that water users generally focus on their own challenges and do not perceive WC/WDM as a priority. In terms of agriculture, not all irrigators are grouped into specific water users, and therefore inhibit interaction on farm level. Many do not have adequate means of metering and measuring water use and the lack of information management systems inhibit the implementation of WC/WDM even further (DWS 2014).

Importantly, there is a general lack of commitment to implement WC/WDM by local authorities and other key role players as WC/WDM is often portrayed as negative and restrictive to consumers. Water service providers also lack the knowledge and understanding of consumer needs and water use patterns. In conclusion, it should be noted that most local authorities do not have the appropriate or necessary information due to inadequate and inappropriate management information systems. The implementation of management information systems as well as the other discussed constraints needs to be kept in mind and be properly addressed for WC/WDM to be effectively implemented.

9.3 Policy Recommendations

Opportunities however far outweigh the mentioned challenges as there are numerous prospects for all sectors, businesses as well as for investments into WC/WDM practices and programmes.

The DWS have dedicated a whole chapter in the second edition of the NWRS on water conservation and water demand management to emphasise the importance thereof. The focus is placed on broad strategies which need to be implemented to reconcile available water supply with the water demand. Water conservation as well as the management of water demand has formed the core to ensure sustainable water use and to ensure sufficient water availability for current and future requirements. The water conservation and water demand management strategies have been developed to be interlinked with the National Water Policy 1997 and the National Water Act 1998 in an attempt to address the country's current water challenges as well as WC/WDM constraints.

Despite some improvement having been made, the governance response does not always seem to align sufficiently with the magnitude of the reported risk of water scarcity in the country. Even though water related risks have increasingly been reported, not all stakeholders such as local government and industries have water policies or strategies in place and even less have set quantitative targets or goals to manage water more efficiently. This apparent disconnect between the high risk exposure and the comparatively lower response measures subsequently indicates that in some cases, South Africa is lacking the required urgency.

The National Water Act (No. 36 of 1998) and the Water Services Act (No. 108 of 1997) form the basis of the country's legislative framework within the water supply and sanitation services, water resource management and water use. Other pieces of legislation which contribute to the defining of the legislative framework include the National Forest Act (No. 84 of 1998), Municipal Structures Act (No. 117 of 1998), Municipal Structures Amendment Act (No. 33 of 2000), Municipal Systems Act (No. 32 of 2000) and the new White Paper on Water Services.

Importantly, the country needs to develop an appropriate policy which addresses natural disasters such as floods and droughts as presently each case is judged on merit and in most cases very little or no governmental aid is given. This task should be completed with sufficient stakeholder engagement by the government with policy makers as well as businesses etc. This creates a baseline message that the costs associated should be part of the irrigator's risk management strategy and the irrigator should be as self-reliant as possible.

Currently some bulk water consumers as well as household consumers are affected by level two water restrictions which oblige them to reduce their water consumption until the restriction is lifted by the relevant water supplier. Appropriate policies therefore have been put in place to reduce water use during water stressed periods however the enforcement of these regulations are lacking and should be improved upon to ensure that water users adhere to restrictions.

From the above discussion the following can be recommended to assist in the country promoting and achieving WC/WDM in all sectors. Firstly, water efficiency targets need to be set and best practices in all water use sectors need to be embedded in the country's legislative framework by the government and local authorities. Water efficiency targets should be set with collaboration of the relevant business stakeholders. This will enable relevant authorities to monitor and enforce appropriate WC/WDM in all sectors and provide an incentive for good performance or penalties for malpractices or not adopting appropriate water efficiency technologies. A regulatory support and incentive framework therefore needs to be developed and incorporated into policy to improve water efficiency and productivity by promoting optimal use of water. Regulations may include progressively higher water prices and taxation based on degree of water inefficiency or losses in terms of households, commercial and institutional sectors as well as in terms of the production of products. Furthermore, tax breaks could be implemented as an incentive for the purchasing of water efficient products and technologies. A grant scheme could also be developed for the installation of rainwater harvesting tanks as well as other water efficiency measures, such as in the case for the installation of energy efficient geysers, to make the implementation of these water efficiency measures more cost-effective.

Measureable water use targets need to be set for all sectors based on the amount of water efficiency or savings which can be achieved (see previous chapters). These targets need to be enforced together with the enforcement of water quality standards in an attempt to increase the urgency to achieve WC/WDM in sectors. An incentive framework should once again be developed to reward companies and other stakeholders for implementing and achieving these set targets. This will hopefully encourage others to do the same. Regulations and by-laws should be incorporated into the legislative framework in terms of the retrofitting of existing plumbing fittings with more efficient ones, decreasing the amount of water used for gardens and pools and lastly to reduce the demand of new consumers through the installment of pre-payment systems. Present regulations and by-laws therefore need to be revised in order to achieve a reduction of water loss through leakages. Once again an incentive framework and/or subsidy or grant scheme can be put in place for domestic, commercial and institutional sectors to adopt water efficiency measures and technologies. These policy recommendations as well as the implementation of the mentioned strategic actions within policy, regulations and by-laws will make the adoption and implementation of WC/WDM a requirement and subsequently assist the country to become less vulnerable to water related problems such as droughts. These actions will hopefully create the necessary buy-in from various sectors to change existing water use behaviours and perspectives to a more WC/WDM outlook.

There are therefore multiple opportunities for businesses in the form of investments as well as the establishment of collaborations with various stakeholders in terms of water efficiency in the country. Sectors should prioritise the calculation of their water footprint in order to reduce water wastage as well as reduce inefficient practices and financial losses. There is a huge opportunity for the investment in the development of innovative water efficiency solutions in terms of irrigation, improved industrial processes through innovative technologies, innovative waste water treatment such as nanotechnology as well as other innovative water efficiency products which could be purchased by domestic, commercial and institutional sectors. Innovative cost effective solutions are therefore urgently needed to reduce water consumption as well as losses but also to improve the desperate water quality situation within the country. Water efficiency is a rapidly growing initiative in which businesses can reap future financial rewards by developing and providing solutions through the development of products or collaborative programmes with various stakeholders. In turn, the implementation of these water efficiency measures will reduce the long term risks accompanied with water stress, ensure that their operations are not affected and limit financial expenses and losses.

Lastly, the development of water efficiency collaborations especially within rural communities can also contribute to the country's future socio-economic growth and have great reputational value on a national, regional and global scale. Businesses should therefore focus on the various strategic actions which can be taken to improve their water usage and consequently decrease their overall risk to water related issues as well as take the opportunity to invest in the development of water efficiency measures and programmes within the country which will be financially rewarding.

Reference

DWS (Department of Water and Sanitation) (2014) National water resource strategy, 2nd edn. Government Gazette, Pretoria

Chapter 10
Conclusions and Evaluations

Water is one of the most widely distributed substances across the world's surface and is crucial for a variety of aspects of human health, development and well-being as well as for the functioning of natural ecosystems. It has been recognised globally as a fundamental human right and needs to be managed both effectively and efficiently to ensure that human and ecological needs are met.

The distribution of water across the globe is uneven and the availability thereof has become a major concern in some regions especially in North Africa and the Middle East. The main water use sectors i.e. agriculture, industries (includes industrial activities, mining and energy) as well as municipal/domestic water use sectors have influenced the world's water resources in terms of availability through physical water abstraction but also through water degradation. Water is the cornerstone for good health and well-being of both humans and ecosystems, but is also a necessity for social and economic development. The quality of the world's fresh water resources have become a global concern due to the significant role it plays in economic and social development.

Water quantity has in the past received far more attention from investors, scientists and the public than water quality. The quality of water is just as important for satisfying both basic human and environmental needs. Poor water quality can also be linked to a decrease in water availability as water that has been polluted cannot be used for agriculture, industry or domestic water usage. Water degradation therefore effectively reduces the amount of water available in that given region.

The world is faced with numerous water quality concerns such as eutrophication, salinization, sedimentation, microbial pollution as well as multiple toxic pollution problems. Poor water quality have been accompanied with economic costs in the form of health-related costs, the degradation of ecosystem functions, high water treatment costs, reduced property values, as well as impacts on economic activities such as agriculture and manufacturing. Therefore water quality problems need to be addressed in order to and maintain satisfactory water quality levels and ultimately lessen human-health related risks and to obtain significant financial savings.

A. du Plessis, *Freshwater Challenges of South Africa and its Upper Vaal River*,
Springer Water, DOI 10.1007/978-3-319-49502-6_10

The limitations in freshwater supply are already present as large areas all over the world are facing the consequences of their dwindling and disappearing water reserves. The uncertain influences of climate change need to be kept in mind as it will also play a role in influencing future water scarcity and stress. The rapid increase in the human population, as well as the increase in water consumption per capita across the globe, has resulted in an increase in water shortages. With respect to global water availability and supply, it is very likely that the costs of climate change will outweigh the benefits globally due to that precipitation variability is very likely to increase, and more frequent floods and droughts are anticipated. Potential conflicts may arise on a local and/or regional level between agriculture, domestic use, industry and the natural reserve. Different types of sub-national conflicts can therefore arise all over the world from water scarcity and be accompanied with immense socio-economic consequences.

Due to global interconnections, water-users in one river basin or catchment area could be strongly linked to other users beyond the borders of the country in question. Water issues have consequently become not only a local issue but rather a global issue as regional and global forces influence the manner in which water is used, as well as the amount used but also the degradation thereof.

The unhindered water use which has grown globally at twice the rate of population growth in the twentieth century, has caused some regions to be no longer able to deliver reliable water services. Water scarcity within South Africa has become a reality and the continued demographic pressure, rate of economic development, high rates of urbanization and pollution will put further unprecedented pressure on the country's water resources. It is estimated that the country's total requirements for water use will double over the next 30 years.

Major industrial development and urban settlement have taken place in regions where water resources are not readily available and have resulted in substantial potential impacts on the quality of water in the country which is already limited in terms of supply. South Africa is consequently facing a multi-faceted water crisis. The mismatch between water supply and water demand, the theft of water resources, a deteriorating infrastructure, the loss of essential skills, a strangling educational pipeline, demand management failure, as well as deterioration in the quality of the water, are all potential threats and key concerns that could lead to the fact that the country is experiencing a water crisis.

The quality of the water in South Africa is affected by both natural processes such as seasonal trends, the underlying geology, weather and climate, as well as by human activities. The most significant water quality issues are salinity, eutrophication, microbial pollution, sedimentation and recently added acidification as a result of the century-long legacy of unregulated gold mining and high density populations living in close daily contact with dust and sediment arising from mine tailings. The significant global water quality issues, as identified by UNEP GEMS, should also be considered as they relate directly to the present pressures on the country's water quality. The pollution of these freshwater resources has been accompanied by a decline in water quality, bringing with it public health issues, but also a reduction in the economic value of the available water. With the continued population growth across the world, investments will have to be made in both developed and developing countries in terms of the improvement and maintenance of water treatment and supply infrastructures, as well as of sanitation facilities.

In terms of the Upper Vaal WMA, the WMA covers a relatively large area and is very important to the South African economy and for future development. The natural landscape has been transformed and manipulated physically and chemically in order to meet society's needs. The changes of land cover and land use have consequently been accompanied by various impacts on the specific region's hydrological responses and ultimately its water resources. The Upper Vaal WMA is highly developed, with the quality of the water varying from poor in developed regions to good in less-developed areas. The water quality in the main rivers, as well as in the tributaries downstream of the Vaal Dam, is affected as a result of urban and industrial return flows and intensive mining activity. Eutrophication, salinisation, microbial pollution, sedimentation and acidification are all significant problems affecting the quality of the water in the Upper Vaal WMA. The large variety of sectors within the WMA have been accompanied with multiple major water-related problems which could in the near future have detrimental effects on the country's socio-economic growth as well as the ecological health of the surrounding environment.

Water shortages are predicted for the majority of large urban areas within the country and interventions will be needed. Currently a large percentage of the country's water is being lost. Climate change will impact the water resources of the southern African region by the increasing variability of rainfall as well as rising sea levels. Both surface water and groundwater will decrease, evaporation will increase leading to soils becoming more salty. Water shortages are expected to affect a large portion of the region's population by 2050 and in terms of South Africa, climate change will pose significant risks to the country's natural assets as well as its human population. Climate change will therefore be accompanied with implications on food security, employment, exports as well as tourism and may lead to tropical diseases such as malaria becoming more prevalent due to the increase of rainfall and temperatures.

Water scarcity or stress can consequently have immense social, environmental and economic implications on all scales. Water related risks have increased and have become significant in all spheres around the globe. In terms of South Africa, the country has also been experiencing an increase in water-related risks mostly due to its water-stressed nature. Short term and long term risks need to be identified and be addressed with the implementation of appropriate measures or solutions.

However, even though water scarcity has been the most reported risk within the country, very few sectors or organisations have measurable water use targets and there is a huge variability in the nature and ambition of targets. This in turn indicates a lack of urgency in terms of water related targets.

South Africa and the Upper Vaal WMA may therefore find itself in a precarious position regarding its freshwater resources within the near future. The increase of water shortages will cause possible conflicts between economic sectors such as agriculture, mining, energy, domestic/municipality as they fight for their share of this declining scarce resource.

A clear understanding of the real potential for reducing water losses is needed before measures are adopted or implemented to avoid costly and ineffective demand management strategies. Various water efficiency measures are available and can possibly be implemented and adopted by the various sectors within the country to promote proper water conservation and water demand management practices. Water efficiency measures however need to be both cost effective and enforced by relevant departments for the country and region to ultimately benefit from implementing water conservation and water demand management measures, targets and structures.

The current challenges which face the water sector of South Africa therefore need to be kept in mind when deciding on and implementing water efficiency measures within the various sectors. Different constraints exist in the variety of sectors of South Africa which may inhibit the adoption and implementation of WC/WDM solutions and measures. There is a general lack of commitment to implement WC/WDM by local authorities and other key role players as WC/WDM is often portrayed as negative and restrictive to consumers. Water service providers also lack the knowledge and understanding of consumer needs and water use patterns and it is concerning that most local authorities do not have the appropriate or necessary information due to inadequate and inappropriate management information systems. The implementation of management information systems as well as the other identified constraints needs to be kept in mind and be properly addressed for WC/WDM to be effectively implemented.

It should however be ultimately emphasised that there are multiple opportunities for businesses in the form of investments as well as the establishment of collaborations with various stakeholders in terms of water efficiency in the country as well as within the Upper Vaal WMA.