UNIVERSITY OF ZIMBABWE

ASSESSEMENT OF THE IMPACTS OF POLLUTION ON WATER QUALITY IN THE CALUEQUE-OSHAKATI CANAL IN NORTH-CENTRAL NAMIBIA.

By

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ABSTRACT

North Central Namibia which is home to almost half of Namibia's estimated 2 million people, like the whole of Namibia is heavily dependent on water sources from neighbouring countries for secure water supplies. A good example is the Calueque-Oshakati Canal which was built to convey water to the Region from the Kunene River in Angola. Due to population expansion, traditional sources of water could no longer meet the water demand in the Region and they increasingly became susceptible to pollution and contamination. There are four water purification plants (Olushandja, Ombalantu, Ogongo and Oshakati) abstracting water from the Canal and distributing it to the surrounding villages and urban centres. The Canal is however exposed to pollution due to poor sanitation and other land use activities in the basin.

The objective of this study was to assess the impacts of pollution on water quality and its subsequent effects on the water suitability for the various intended uses (Aquaculture, irrigation and potable use) and its implications on the water purification processes. Water samples were collected at four points along the Canal from February to April 2008 with the furthest sampling point upstream situated at the Canal entry into Namibia borders and furthest point down stream located at the end of the Canal. The following physico-chemical and biological parameters were determined: temperature, dissolved oxygen, pH, turbidity, total dissolved solids, sodium, Calcium, Magnesium, total hardness, Nitrate, and Escherichia coli. Water treatment plant performance data for the year 2006/2007 of the four water purification plants were obtained from NAMWATER with monthly average values of pH, turbidity, coagulants and chlorine used, and the cost of chemicals used. Jar tests were also carried out to confirm the impacts of pollution on water purification process.

Water samples were collected at four points along the Canal from February to April 2008 with the furthest sampling point upstream situated at the Canal entry into Namibia and furthest point down stream located at the end of the Canal. Temperatures at all stations averaged between 24ºc and 26.7ºc, dissolved oxygen averaged between 3.9 and 4.7mg/l at all sampling stations, pH values averaged between 6.9 to 7.6, turbidity averaged 111NTU upstream and 243NTU down stream. Total dissolved solids concentrations were 43mg/l upstream and 68mg/l down stream, total hardness was 15mg/l as $CaCo_3$ upstream and 24mg/l as $CaCo_3$ downstream while nitrate concentrations both up stream and down stream were below 0.1mg/l. and E.coli averaged 4 Most probable number per 100ml (MPN/100ml) upstream and 42 MPN/100ml. Jar test results indicated that chemical dosages increased from upstream to down stream treatment plants, Olushandja, 16mg/l, Ombalantu 18mg/l, Ogongo 29 mg/l and Oshati 38mg/l.

Despite the increase in parameters concentration from upstream to downstream, most parameter concentrations were within the permissible limits of NAMWATER standards and the WHO guidelines for drinking water and the water was found to be suitable for the various intended uses except, as a direct source of potable water. The jar test results shows that treatment plant further downstream use high dosages of coagulants to purify the water compared to those further upstream, this could be attributed to the cumulative impacts of pollution.

DEDICATION

This project is dedicated to my Mother. Thanks mom for always being there, keeping strong and keeping us all grounded.

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ABBRIVIATIONS AND ACCRONYMS

AWWA	American Water Works Association
C	Concentration
DM	Deusche Mark
DO	Dissolved Oxygen
E. coli	Escherichia coli
EC	Electrical Conductivity
EIS	Etunda Irrigation Scheme
EPA	Environmental Protection Agency
IBT	Interbasin Water Transfers
Km	Kilometres
LHWP	Lesotho Highland Water Project
MFMR	Ministry of Fisheries and Marine Resources of Namibia
MPN/100 ml	Most Nrobable Number per 100ml
N$	Namibia Dollars
NAMWATER	Namibian Water Corporation
NOM	Natural Organic Matter
NPS	Non-point pollution sources
NTU	Nephelometric turbidity unit
OAF	Omahenene Aquaculture Farm
OBP	Omahenene Border Post
OWTP	Oshakati Water Treatment Plant
PL	Pollution Load
Q	Discharge
RSC	Residual Sodium Carbonate
SADC	Southern African Development Community
SAR	Sodium Absorption Ratio
SOER	State of the Environment Report
TDS	Total Dissolved Solids
UN	United Nations
UNEP	United Nation Environmental Programme
USD	USA Dollars

CHAPTER ONE

1.0. INTRODUCTION

Comprising over 70% of the Earth's surface, water is undoubtedly the most precious natural resource that exists on our planet. It sets the stage for the evolution of life on earth and is an essential ingredient of all life today (Marowski, 1992). There is no other resource that affects so many areas of the economy or of human and environmental health like water (Tavera, 2000). In view of this fact one would expect human beings to have the utmost respect for the resource and safe guard its cleanness. Yet throughout the world people are remarkably short sighted and negligent in this regard.

Water has been accorded high priority in the global development agenda. At the Johannesburg World Summit on Sustainable Development in 2002, countries were required to develop IWRM and water efficiency plans in order to reverse the current trend in water resources degradation and to achieve integrated management of land, water and living resources, while strengthening national capacities (Abidin, 2004). The recommendations and principles from Agenda 21 cover water resources management in general, i.e. including availability of water, demand regulation, supply and tariffs. Water pollution control should be considered as a subset of water resources management as water management entails two closely related elements, which are the maintenance and development of adequate quantities of water at adequate quality (Larsen *et al.,* 1997). Thus water resources management cannot be conducted properly without paying due attention to water quality aspects.

Degradation of surface and groundwater sources has previously been an inherent consequence of economic development and remedial action to compensate for, or to reduce, environmental impacts have always been a lesser priority (Larsen *et al.,* 1997). Preventing pollution is significantly less expensive than paying fines and clean up costs. According to the United States Environmental Protection Agency (EPA) Americans spent U$ 140 billion a year to control and clean up pollution (Marquita, 1997). A study in Harare indicated that the raw water quality in the city had deteriorated and for this reason chemical usage in treating the water has increased, in 1991 for example only 35-40g of Aluminium Sulphate treated 1m^3 of water. In 1992 this Figure increased in to 75-80g and in 1995 to 100g (Maya, 1996). The amount spent on acquiring chemicals to treat water constitutes a huge part of any water utility's expenditure. NAMWATER (the Namibian water utility) spends millions of Namibia dollars (N$) on water treatment chemicals for example in 2003/2004 they spend N$ 52 millions (7.4 million USD) to purify 11 160 834.50 m^3 water in the Cuvelai and Kunene areas alone (Namwater, 2008). The amount spend on chemicals rises with the deteriorating water quality and this in turn makes water expensive, as the water utilities are forced to adjust water prices to recover costs. Paying for water in Namibia seems expensive already, based on the frequency that NAMWATER cut off communities' water supplies due to non payment.

The world is increasingly forced to face the challenge of how to ensure access to adequate water resources for the expanding populations and economies. One increasingly popular way governments ensure distribution of water evenly across the country is by transferring it from areas with perceived surpluses to those with shortages (Shao and Wang, 2003). According to WWF (2007) water transfers schemes are often expensive, elaborate, and unsustainable ways that complicate, not solve water problems. Rather than solve water shortages they often become drivers for unsustainable water use. Namibia is heavily dependent on its neighbouring countries for securing its water supplies, particularly on South Africa and Angola (Kundell, 2007). North-central Namibia is dependent on water transferred from the Kunene River to the Cuvelai Etosha basin through the Calueque-Oshakati Canal.

This study set out to assess the impacts of pollution in the Calueque- Oshakati Canal and how it affects the suitability of the water quality for various intended uses (agriculture, fisheries and domestic) by analysis of physical, Biological and chemical water parameters that most affect the different water uses. The study also determined the impact of pollution in Calueque- Oshakati Canal on the water purification process by focusing on the amount of chemicals used to purify water at the four water treatment plants abstracting water from the Canal.

1.1. Background

This study was conducted in the Cuvelai Etosha basin, north-central Namibia, a basin shared with Angola. The basin is made-up of a network of interconnected water channels originating in the highlands of central Angola, flowing southward into Namibia forming a massive inland delta which funnel towards Etosha pan (Niipele and Klintenberget, 2006). The Cuvelai Etosha basin is subdivided into four political regions of Omusati, Oshana, Oshikoto and Ohangwena and into four sub-basins; Tsumeb, Cuvelei-Iishana, Niipele-Odila and Olushandja, the Canal is entirely located in the Cuvelei-Iishana sub-basin. Figure 1 is a map showing the Namibian part of the the Cuvelai with Cuvelei-Iishana sub-basin indicated in yellow.

The Cuvelai Etosha basin is home to about 800 000 people, making up almost half of Namibia's total population (Niipele and Klintenberget, 2006). The semi-arid climate in the Cuvelai Etosha basin coupled with the highest population growth and density in Namibia made it inevitable to secure a new source of water supply, as traditional sources could no longer meet water demand in the basin. In line with a Water Master Plan for Namibia of 1974 a 154 km long Calueque-Oshakati Canal was built to transport water to the basin from the Calueque Dam on Kunene River inside Angola (Heyns, 2006). The Canal supply water to about 30% of the northern population, Livestock are believed to account for 80% of all water demand in northern Namibia; much of this demanded is being met by the pipeline (Eales *et al.*, 2003). The exact figures of water demand in the Region proved hard to find. There are four treatment plants along the Canal, Olushandja, Ombalantu, Ogongo and Oshakati distributing water to the surrounding villages and urban centres with a network of pipes of about 2600 km in length (Mendelson *et al.*, 2002). Despite this some people along the Canal use the water for domestic purposes and in some extreme cases as direct source of drinking water more especially when water supply is cut off due to no-payment.

The major land use activity in the area is agricultural including livestock farming and use of water from the Canal for stock watering is common. In the year 2000 there were an estimated 85 000 homesteads in the basin and almost 98% of households in urban areas had access to clean water compared to 67% in rural areas (Mendelson *et* *al.*, 2002). Omusati Region had 83% of households with no sanitary facilities compared to Oshana that had 49% (Census office, 2001). According to as study by WHO (2006) the Omusati Region through which the Canal pass has one of the highest number of Namibia's estimated 200,000 people (14%) infected by *schistosomiasis*. The prevalence of the parasite in the Omusati and Oshana coincided with the building of the Canal. The spread of the disease is generally attributed to lack of potable water and adequate sanitary facilities (WHO, 2006).

Currently development in the Catchment areas of the Kunene is still limited, largely due to the Angolan civil war; therefore the quality of water reaching Namibia is still unpolluted. However human influence on these rivers once they reach Namibia is increasing, and recent studies on the insects and other aquatic organisms inhabiting the Kwando River showed a decline in recent years (Anonymous, 2001) which is indicative of pollution. The Canal is subject to pollution from solid wastes, human and animal faecal materials mostly from urban, surrounding villages and agricultural runoff.

1.2. Problem identification

According to UNEP (2005) although new assessment and management technologies have been applied and new strategies adopted, problems of water pollution and degradation still persist and, in some areas are on the rise. The WHO estimated unsafe water and poor sanitation to cause 80% of all diseases in the developing world (Miller, 2000). Metallic contaminants and microbial pollution are serious concerns in many water bodies around the world (UNEP, 2006). According to Anonymous (2001) water pollution is the single most important facet of pollution in Namibia, because of the prevailing aridity, water is the most significant factor limiting sustainable development.

According to the Anonymous (2001) the water reaching Namibia especially from Angola is unpolluted however human activities inside Namibia are polluting these water resources. According to (Dragnich *et al.*, 2007) people living near the Canal have the tendency of breaking the Canals and draw free unpurified water for consumption and livestock, others use the Canal to swim, wash clothes or fish. The extent of the pollution is not extensively studied as applied research in Namibia is only carried out when there is need for quick answers (SADC, 1996). The Ministry of Environment and Tourism (undated) noted that there is lack of data on water quality and there is need to update the water quality databank by ensuring frequent sampling for water quality on the perennial, ephemeral rivers and dams.

1.3. Justification

The pollution of surface and groundwater through mismanagement of solid waste or other mechanisms such as human and animal faecal material deposited directly in water or arising from inadequate sewage works is the major form of water pollution in Namibia (Anonymous, 2001). This applies especially to peri-urban areas, and other settlements which have developed with no proper water supply and sanitation services. Water pollution contributes towards more scarcity as the water may be polluted to levels where it is becomes very expensive to treat. The consequence of both water scarcity and high treatment cost will be an increase in the water price. According to The National planning commission (2008) Namibia represents a typical dualistic economy where abject poverty exists alongside extremes of wealth. In 1993/94, 37.8% of households were classified as poor with food accounting for 60% or more of their household expenditure and 9% extremely poor with food accounting for 80% or more of the house hold expenditure. Water prices increases will lead to the further marginalisation of these households as they will be required to increase the mount spent on basic needs.

The results from this research will contribute to the maintenance of the water quality needed for agricultural, fisheries and for potable use which will contribute to sustainable development in the basin. It is hoped that the research will further contribute to wards achieving the Millennium Development Goal 7, target 10 which is to halve by the year 2015 the proportion of people without access to a suitable water source and sanitation. This will be possible if water treatment costs are reduced by maintaining good water quality; then the extra resources can then be channelled towards improving access to water and improve sanitation. The provision of adequate safe water will curb the prevalence of *schistosomiasis* as recent studies have shown that populations with safe public water supplies can have up to 40% lower incidence of the disease than those without (Gorchev, 1996).

1.4. Study objectives

The main objective of this study was to assess the impacts of pollution in the Caluque-Oshakati Canal and assess the suitability of the water for its intended uses.

1.4.1. The specific objectives:

1. To determine the impact of pollution on the suitability of water from the Calueque-Oshakati Canal for various uses (irrigation, fisheries and potable use).
2. To identify and quantify the different sources of pollution along the Calueque-Oshakati Canal.
3 To assess the impacts of pollution on water treatment, focussing mainly on chemical consumption.
4. To develop intervention measures to reduce pollution in the Canal.

1.5. Scope of study

The study was based on the surface water in the Canal as it enters the Namibian borders from Angola. The impact of anthropogenic activities on the quality of water was determined. The water quality was compared to generally accepted standards to determine the water suitability for the various uses. The study also looked at the past data from NAMWATER of the four treatment plants along the Canal as basis of comparing the impact of pollution on the water purification process using the amount of coagulants, disinfectants and cost of chemicals per m^3 as indicators.

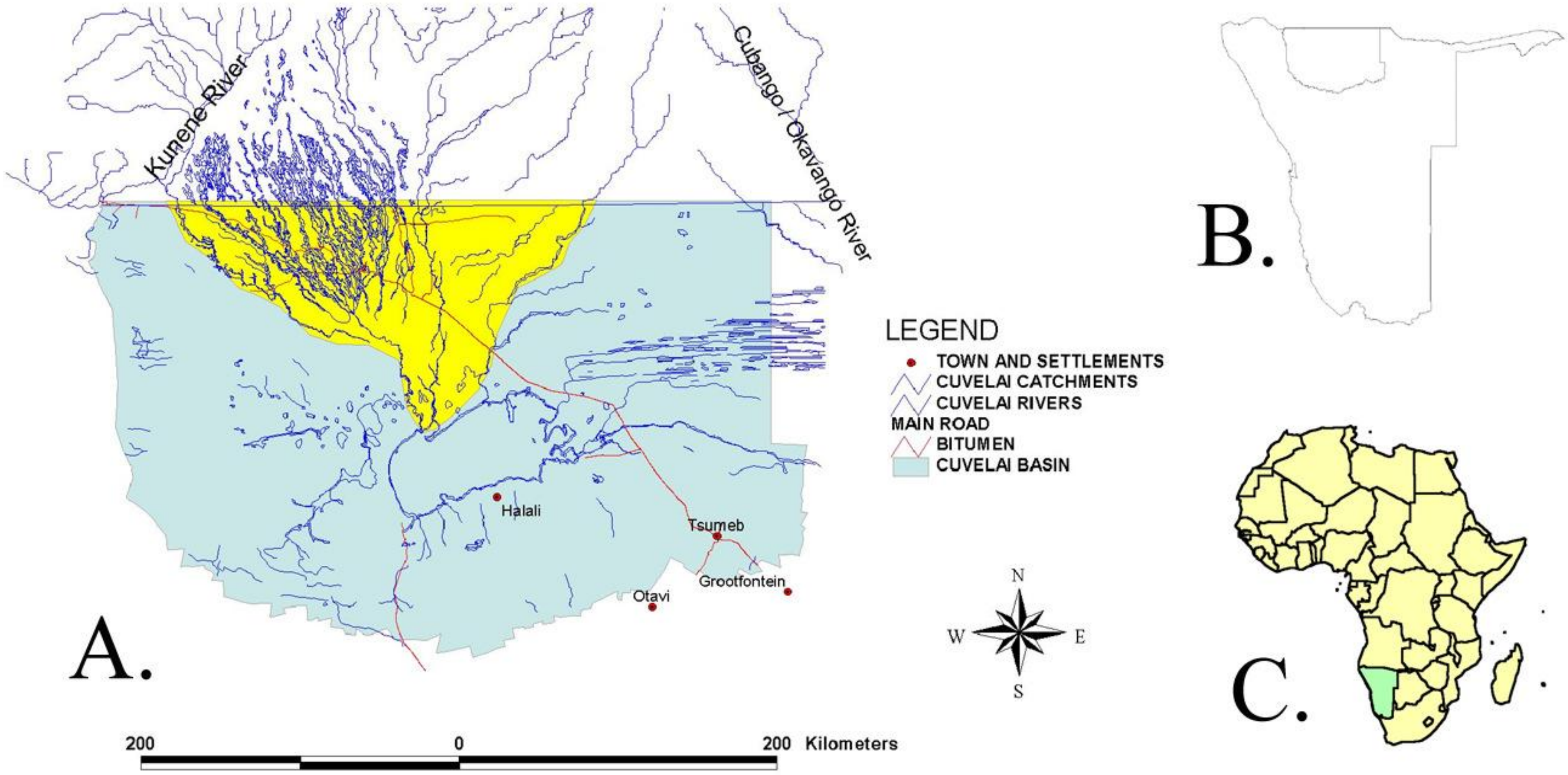

Figure 1: Map A shows the Namibian part of the Cuvelai Etosha basin (the study area) and the Iishana subbasin indicated in yellow. Map B: the study area in Namibia, and Map C: Namibia's location on the African continent. (Source: Niipele and Klintenberget et al., 2006)

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Fresh water availability from a global perspective

Globally the demand for water varies remarkably between countries; this depends on the population, prevailing levels and patterns of socio economic development, marked differences exist between developing and developed countries. For example the average per capita domestic use in the United States of America is more than 70 times that in Ghana (UNEP, 1992). Water supplies continue to dwindle because of resource depletion and pollution, whilst population growth and expansion in industry and agriculture further exacerbate the problem of water scarcity. Contentious competition for the water of international rivers such as the Nile, the Jordan and the Ganges is a symptom of the increasing scarcity of water (Marowski, 1992). In the South African Development Community (SADC) the distribution, occurrence and availability of water resources is uneven in the region and within individual countries, the water availability depends on the rainfall (SADC 1996).

There is a marked difference in water consumption at both global and regional levels. There is also an increasing trend of water scarcity leading to competition amongst different water users as well as amongst nations.

2.2. Namibia's water resources

In Namibia water is increasingly becoming scarce a fact compounded by two hard realities (Mendelson *et al.*, 2002). The first is the general scarcity of water due to low, sparse and variable rainfall coupled with high evaporation rates. The second is that a large number of people are concentrated in areas far from the major sources of water. Rainfall patterns are characterised by high temporal and spatial variability. Namibia has a mean annual rainfall of 285 mm. Of the total rainfall; 83% evaporates, 14% is used up by vegetation, 1% recharges ground water and 2% becomes runoff (Namibia Resource Consultants cc (undated).

The total renewable water resources of Namibia are estimated at 45, 46 km^3/yr; of which only 6.16 km^3/yr are internally produced (Kundell, 2007). Agriculture is the Number One water user, followed by domestic use and industry. For example in the year 2000 Namibia's water consumption was 300 million m^3 agriculture used 213 million m^3 (71%), the domestic sector 73 million m^3 (24%) and industry 14 million m^3 (5%) according to Kundell (2007).

The major portion of Namibia's total renewable water supply originates beyond its borders.

2.3. Interbasin transfers (IBT)

Shao and Wang (2003) noted that in large countries with sharp temporal and spatial variation in water resources, inter-basin water transfer projects seem to be an ultimate solution to ease water shortage and secure a balanced economic development among different regions. WWF Global Freshwater Programme (2007) argues that big or small, transfers schemes are often expensive, elaborate, and unsustainable ways that complicate, not solve, water problems. Rather than solving water shortages they often become drivers for unsustainable water use. In Southern Africa an examination of inter-basin water transfer projects, pointed out that despite the high costs, the ecological and social implications of such schemes are inadequately addressed (Shao and Wang, 2003).

According to Shao and Wang (2003) a study proved that parasitic diseases, such as *schistosomiasis*, could proliferate due to transfer from the infected area. A study in China found that during the period of 1989–1998, a total of 7772 cases of acute *schistosomiasis* infection were reported in Hubei Province alone. It was found that drifting pieces of reed carrying snails from the infected area could lead to the development of new snail habitats in the riparian area of lower reaches of the Yangtze River.

It seems that IBT's do not solve water problems but complicate them. Besides the spread of water borne diseases IBT has several other negative impacts which include environmental and social problems.

2.4. Pollution Regulations and legal framework in Namibia

At Independence, Namibia inherited environmental legislation that was outdated, fragmented and incomplete. As a result, it became necessary to revise and review the existing environmental legislation. As far as water resources management is concerned, the Government of Namibia embraced the concept of integrated water resources management (IWRM) as propagated by the four 1992 Dublin Principles. A new National Water Policy was adopted in August 2000 (Government of the Republic of Namibia, 2000). This policy concentrated on resources management issues and instead of replacing the 1993 Water Policy, it complemented it. The new national water policy, lead to the enactment of the Water Resources Management Act of 2004 (Government Gazette, 2004). The water resources management acts in parts provide for water pollution prevention, it states that:

1. No discharge of effluent without permit
2. No discharge from sewer without permit
3. Standards of effluent should be of a certain quality
4. Declarations of water management area to safe guard it from all kinds of threats.

The Water Resource Management Act of 2004 is more concerned with water pollution from point sources. It does not provide provision for pollution prevention from non-point sources of pollution and from general waste. However these aspects of pollution prevention are provided for by the draft Pollution Control and Waste Management Act. This act provides for the formation of the pollution control agency that will have powers to enforce this act. In terms of water pollution prevention the agency will be responsible for:

1. Water quality monitoring and co-ordination.
2. Recommending to responsible minister on formation of regulations to establish standards, objectives or requirements in relation to water quality and activities liable to cause water pollution.
3. The agency will be responsible for setting up water quality action areas, where it is necessary to reduce levels of water pollution so as to ensure compliance for human and environmental protection.

4. The agency will be responsible for issuing, monitoring and enforcing of permits of discharge of pollutants or waste to water or watercourses based on the polluter pays principal.

The drafted Pollution Control and Waste Management Act have a provision for an integrated pollution control when a process creates a risk of pollution to more than one environmental medium. Currently uncomplicated waste management practices are used in Namibia. In rural areas, waste management is carried out by individuals. In some areas a newly proclaimed local authority or a regional council may establish a designated waste site (Anonymous, 2001).

2.5. Water pollution

Scholars have varied definition of water pollution, John (1970) noted that the term pollution does not only have different meanings amongst people but has also become emotionally charged. Dr. Author has defined as when river water is altered in composition or condition, directly or indirectly as a result of the activity of man, so it becomes less suitable for any or all the other uses for which it would be suitable in the natural state. Ellis (1989) reasons that there is no such a thing as pollution; it is merely a problem of having valuable chemicals in the wrong place at the wrong time. While Nilgun (1992) define water pollution as the addition of something to water which changes its natural qualities so that the riparian owner does not get the natural water of the stream transmitted to him. The first and third definitions both acknowledge the alteration of the characteristics of water as a result of human impacts. However the first definition was more encompassing compared to the last two by acknowledging that pollution reduces suitability of the water for certain uses. The author views pollution as consequence of human activities deliberate or otherwise that cause the decline in the quality of natural waters reducing its usefulness for certain uses.

The lack of sanitation and sewage treatment is the biggest factor regarding water pollution. Water bodies are used as dumping grounds for untreated water from urban areas or industries. According to the UN World Summit (2002) it was estimated that each year roughly 450 000m^3 of wastewater were discharged into rivers, lakes and streams around the world. To dilute and transport this polluted water a further 6million (m^3) of water was needed. The Food and Agriculture Organization of the United Nations (FAO) estimated that if current trends continued, by the middle of the 21st century the world's entire normal river flow will be needed just to transport and dilute polluted water (UN world summit 2002).

Fresh water resources in Southern Africa are under pressure from pollution and water quality is a growing concern, particularly in urban areas and close to industrial centres (UNEP, 2000: SADC, 1996). Jenkins (1972) and SADC (1996) noted that with the growing urban and industrial use of the water, greater amounts of organic and inorganic wastes are spewed back into the water sources leading to diminished water quality. Given the high levels of pollutants from agriculture, industry and house holds in southern Africa, river systems are no longer able to effectively cleanse themselves (SADC, 1996). Lake Chivero near Harare experienced algal blooms, infestations of water hyacinth and fish deaths as a result of high levels of ammonia and low oxygen levels attributed to sewage contamination from near by settlement as well as agricultural runoff (UNEP, 2002).

The reduction of pollution, protection of water resources as well as preserving its quality is not often seen as a priority in developing countries that it should have (Zambezi Basin, 2000). Bad water quality limits people's level of living, about 35 % of the deaths in the world are caused by water-borne diseases and diseases transmitted by vectors living in the water environment (UNEP, 2002). Water quality is important for agriculture, industry, and tourism. When plants and crops are irrigated with polluted water, the pollutants may contaminate the plants and can be carried to humans through eating them, this contamination can also happen in fishes and other animals. Polluted water may spread diseases or death to the farmers working with the contaminated water (Environment and Urbanization, 2002).

Although there are varied definitions of water pollution is there seem to be a consensus amongst scientists that it is an alteration of the characteristics of water as a result of human activities and this reduces the suitability of the water for certain uses.

2.5.1. Causes of water pollution

Water pollution is caused by discharge from sewage, discharge from manufacturing and industrial plants including mining discharge from animals rearing, fish farming and agricultural activities and seepage from domestic and industrial land fill sites. The sources of pollution are categorized into two types, point and non point sources of pollution.

- *Point sources*

According to Marquita (1997) point source pollution is from a single identifiable source discharging pollutants at specific locations through pipes, ditches, or sewers into bodies of surface water. Examples include factories, sewage treatment plants (which remove some but not all pollutants), active and abandoned underground mines, etc. Because point sources are at specific places, they are fairly easy to identify, monitor and regulate.

- *Non-point source*

Non-point pollution sources (NPS) are low-concentration sources covering a large area, NPS pollution, occurs from a large area as opposed to a small number of well defined points (Davis and Hirji, 2003). According to Allen et al (1971) storm water runoff from agricultural land carries silt, clay, fertilizers, pesticides as well as organic material and bacteria into water courses. Non-point sources of pollution have been identified as the main cause of water pollution in many countries. Ninety percent of impaired water bodies do not meet water quality standards due to non-point source pollution (Marquita, 1997). Although non-point sources of pollution have been identified as the main cause of water pollution in many countries, however non-point source pollution control has failed to realize the same reductions as point source of pollution. Heal (2007) noted that this is the case because non-point sources are difficult to control and manage; he further noted that the long-term solution to this problem is changes in land use and management. Allen (1989) and Chowdary et al. (2001) concurred that greater emphasis has been placed on regulating toxic substances and on treating of hazardous waste.

There seems to be different views as to the reason non-point sources of pollution has failed to realise the same levels in reduction pollutant reduction as point-sources.

Some scientist seems to imply that it's because it is difficult to control and the others because it has been neglected in terms of research.

2.5.2. Natural processes affecting water quality

According to UNEP (2004) without human influences, water quality would be determined by the weathering of bedrock minerals, by the atmospheric processes of evapo-transpiration and by the deposition of dust and salt by wind, by the natural leaching of organic matter and nutrients from soil, by hydrological factors that lead to runoff, and by biological processes within the aquatic environment that can alter the physical and chemical composition of water. Certain natural phenomena results in water quality falling below that required for particular purposes. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landslides, which in turn increase the content of suspended materials in affected rivers and lakes. A study by Booth *et al* (1994) concluded that while the rainy season provides water to dilute pollutants, flooding from intense rain can make pollution worse, storm water dissolve pollutants on the ground and carry them into the water supplies.

The phenomenon of water pollution through the natural processes is beyond man's resolve, but the introduction of other pollutants by man could cause an imbalance in the ecosystem.

2.6. Impacts of pollution on water quality

Pollution by agricultural run-off especially from pesticides have effects on the environment, they are especially difficult to remove from freshwater, and thus, can be found in municipal or bottled water, even after conventional treatment (Augustin, 2003). Pollution also has detrimental impacts on water quality which in turn increase the cost of municipal water treatment. The costs and difficulty of removing contaminants can be considerable, depending on the materials to be removed; some contaminants are not easily treated. Maya (1996) noted that the quality of water delivered to the consumers is a function of various factors, one of them being the quality of raw water. This observation was further echoed by Tolman (1997) who concurred that the cost of municipal water treatment due to diminished water quality represents an important component of the societal costs of water pollution.

Water pricing is a barrier to access to safe and adequate water for drinking and sanitation by poor people. A study by the UN world summit (2002) concluded that in developing countries, people may pay up to 30% of their income for water supply and treatment compared to the United States where people pay about 1-2% of their house hold income for water supply and treatment. According to Manuel et al. (1999) the situation in developing countries is even worse since for comparable pollution problems and ever greater water scarcity conditions, the available financial means are much smaller A study by Tolman, (1997) for Texas show that when raw water is contaminated, the chemical cost of water treatment is increased by USD 95 per million litres from a base of USD 75. The same study also found that 1% increase in turbidity is shown to increase chemical costs by one fourth of a percent.

Literature shows that certain pollutants, especially from pesticides are difficult to remove from water even with conventional water treatment. The quality of raw water determines the cost of the water treatment in terms of chemical consumption.

2.7. Impacts of water pollution on different water uses

With the advent of industrialization and increasing populations, the range of requirements for water have increased together with greater demands for higher water quality (Chapman, 1996). There are water quality standards that must be met for different types of uses. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water; for example limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities (Hammer *et al.,* 2001). Water quality can be defined by a range of variables which limit water use (Bartram *et al.,* 1996).

To consider water for irrigation or any other use, there must be sufficient quantities at a quality that is compatible with the different uses. In addition, constituents that can damage infrastructure or pose danger to humans and aquatic life must be absent or economically removable.

2.7.1. Impacts of pollution on the water suitability for Agricultural use

Where the available soil moisture derived from rain is deficient this inadequacy can be made up by irrigation (George 2004). The primary objective of irrigation is to provide a crop with adequate and timely amounts of water, thus avoiding yield loss caused by extended periods of water stress during stages of crop growth that are sensitive to water shortages. Poor quality water may affect irrigated crops by causing accumulation of salts in the root zone, by causing loss of permeability of the soil due to excess sodium or calcium leaching, or by containing pathogens or contaminants which are directly toxic to plants or to the consumers (Enderlein and Williams, undated). Water quality criteria for irrigation water generally take into account, amongst other factors, such characteristics as crop tolerance to salinity, sodium concentration and phytotoxic trace elements. There are two most important measures for determining irrigation water quality according Gordon (2007) and Hopkins (2007), the total amount of dissolved salts in the water and the amount of sodium in the water compared to calcium plus magnesium (sodium absorption ratio).

- *Salinity*

Kuchanwar *et al* (1999) defines salinity of irrigation water as the total concentration of dissolved salts in it. There are two common water quality assessments that characterise the salinity of irrigation water, total dissolved solids (TDS) and electrical conductivity (EC) Grattan (2002). Salts that are dissolved in water conduct electricity therefore; the salt content in the water is directly related to the EC. According to Grattan (2002) and Fipps (2003) Conversions between ECw and TDS are made using the following formulae:

- TDS (mg/l) = 640 * ECw (ds/m) when ECw < 5 ds/m
- TDS (mg/l) = 800 * ECw (ds/m) when ECw > 5 ds/m

DeHayr (2006) noted that one of the major concerns with water used for irrigation is decreased crop yields and land degradation as a result of excess salts being present in the water and in the soils. As irrigation water is applied to the soil the total concentration increases as the water is lost through plant transpiration and evaporation. Excessive accumulation of soluble salts and/or sodium in soil causes water stress for crops by plugging clay and humus into soil pores reducing the ability for the crops to extract water from the soil (Fipps, 2003). A study by George (2004) found that applying 1000mm of water containing 1000mg/L total dissolved solids, to a hectare of land, applies 10 tonnes of salts. Water with total dissolved salt content below 160mg/l is considered to have very low hazard and have no detrimental effects on plants, and there is no soil build-up expected. Water with total dissolved salt content above 1920mg/l are considered to have a high hazard and are generally unacceptable for irrigation, except for very salt-tolerant plants where there is excellent drainage, frequent leaching, and intensive management (Hopkins, *et al.,* 2007) refer to specific salt tolerance of crops farmed at Etunda is given in Table 1A in Appendix A for the general hazard from salinity in irrigation water.

Salinity seems to be a major concerns regarding irrigation water quality, Salts in soil or water reduce water availability to the crop to such an extent that yield is affected.

- *Sodium Absorption Ratio (SAR)*

Sodicity of irrigation water may be defined as the extent of dissolved sodium that can possibly determine the soil physical condition and pose infiltration and permeability problems, ultimately affecting the plant growth (Ayers and Westcot, 1994). The major criteria often used to evaluate irrigation waters from sodicity point of view are Sodium Adsorption Ratio (SAR). SAR value measures the relative concentration of sodium to calcium and magnesium, the higher the SAR the greater the risk of damaging soil (DeHayr, 2006). Equation 1 presents the formula to calculating SAR. According to Fipps (2003) continued use of water having a high SAR (above 13) leads to a breakdown in the physical structure of the soil. Sodium is adsorbed and becomes attached to soil particles. The soil then becomes hard and compact when dry and increasingly impervious to water penetration. Fine textured soils, especially those high in clay, are most subject to this action. Refer to Table 2A in Appendix A for sodium hazard of water related to SAR.

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{1}{2}([Ca^{2+}]+[Mg^{2+}])}} \quad \text{--Equation 1}$$

SAR is responsible for soil structure stability, with continuous use of the water with SAR value above 13, leads to break down of the soil's physical structure. This causes the soil to become hard and compact when dry which decreases water infiltration into the soil.

2.7.2. Impacts of pollution on the water suitability for Fisheries use

According to UNEP (2006) Fish are important not only for ecosystem function, but also may provide socioeconomic value in the form of fishery resources for people. Loss of fish species due to changes in water quality or over-fishing may result in dramatic shifts in ecosystem dynamics, as grazing pressure on invertebrates and algae can be released, enabling rapid growth and potential blooms of algal populations. Fish are important for assessing contaminants in ecosystems since they generally represent the top of the food chain. Fish are totally dependent upon water to breathe, feed and grow, excrete wastes, maintain a salt balance, and reproduce; understanding the physical and chemical qualities of water is therefore critical to successful fisheries.

According to LaDon (2007) Dissolved oxygen (DO) is by far the most important chemical parameter to fish and other aquatic organisms. Low-dissolved oxygen levels are responsible for more fish kills, either directly or indirectly, than all other problems combined. According to U.S. EPA's water quality criteria; the one-day minimum for cold-water species is 5mg/l in early development stages and 4mg/l for other stages. For warm water species, 5mg/l and 3mg/l is needed in early and other stages, respectively (Aull 2005). After oxygen, water temperature may be the single most important factor affecting the welfare of fish. Fish are cold-blooded organisms and assume approximately the same temperature as their surroundings (SEED, 2003). The temperature of the water affects the activity, behavior, feeding, growth, and reproduction of all fishes.

It seems that dissolved oxygen and temperatures are the two most critical water parameters to fish, with warm water species requiring between 3-5mg/l depending on their life stage.

2.7.3. Impacts of pollution on the water suitability for Potable use

Access to safe drinking-water is important as a health and development issue at a national, regional and local level (WHO, 2006). WHO sets the recommendations for each measurement that must be followed by each country depending upon health and conditions in that country and the state of its economy the goal is to establishing national standards.

Safe drinking-water, as defined by the WHO guidelines for drinking water, does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. The Ministry of Health and Social Services and the Ministry of Agriculture, Water and Forestry are the agencies responsible for setting water quality standards for drinking water in Namibia.

2.8. Physical, chemical and biological water parameters

2.8.1. Temperature

Water bodies undergo temperature variations along with normal climatic fluctuations (Chapman, 1996). These variations occur seasonally and in some water bodies over a period of 24 hours. The temperature of surface water is influenced by latitude, altitude, season, time of day, air circulation, cloud cover and the flow depth temperature ranges of surface waters range from 0- 30ºC hot springs can reach 40ºC (Chapman, 1996). The metabolic rate in of aquatic organisms is related to temperature, in warm waters respiration is rates increase leading to increased oxygen consumption and decomposition of organic matter. The rates of chemical reactions tend to double for each every 10°C rise in temperature (AWWA, 1990). Temperatures significantly affect the dissolving of $CaCo_3$, less $CaCo_3$ dissolve at higher temperatures and this excessive precipitate can clog hot water lines (AWWA, 1990). Temperature is important in aquatic systems because it can cause mortality and it can influence the solubility of dissolved oxygen (DO) and other materials in the water column such as e.g., ammonia which is poisonous to fish (UNEP, 2006). According to the AWWA, (1990) temperature plays an important role in turbidity removal by metal-ion coagulants; decreased removal occurs at lower temperature and lower temperature also affects coagulation and flocculation process by altering coagulant solubility, increasing water viscosity, and retarding the kinetics of hydrolysis reactions.

Temperature is influenced by many factors such as latitude, altitude, season, and time of day, air circulation, cloud cover and the flow depth. Water temperature plays a part in chemical reactions in the water with increases in temperature associated with increased chemical reactions.

2.8.2. Dissolved Oxygen

Dissolved oxygen (DO) is a measurement of the amount of oxygen gas dissolved in water, and available for use by plant and aquatic species (WHO, 2006). The oxygen content in natural water varies with temperature, salinity, turbulence, the photosynthetic activity of algae and plants, and the atmospheric pressure (Chapman, 1996). Oxygen gas naturally mixes with water through surface interaction; Fast moving waters typically have a higher DO due to mixing with air when the water hits debris such as rocks and logs. Oxygen concentration in natural running waters should be close to 100% saturation, that is, between 9mg/l and 11mg/l depending on temperature while concentration in unpolluted waters is usually close to but less than 10mg/l (SEED, 2003).

According to O'Neill *et al.* (1994) dissolved oxygen concentrations in drinking water produce no adverse physiological effect on humans; however, adequate amounts of dissolved oxygen must be available for fish and other aquatic animals. Different species and sizes of fish require different amounts of DO to thrive. Based on the U.S. EPA’s water quality criteria, the one-day minimum for cold-water species is 5mg/l in early development stages and 4mg/l for other stages. For warm water species, 5.0 mg/l and 3mg/l is needed in early and other stages, respectively (Aull, 2005).

Oxygen concentration in unpolluted water is close to but less than 10 mg/l, while in running natural waters DO should be close to 100% saturation (between 9-11 mg/l). DO have no health impacts on humans but an aquatic organism requires certain DO concentrations.

2.8.3. Water pH

The pH is a measurement of how acidic or how basic (alkaline) a solution is (Mesner, 2005). Water pH is closely linked to biological and chemical processes within a water body and all processes associated with water supply and treatment (Chapman, 1996). The pH is measured on a scale from 1.0–14.0 with no units, where more basic solutions have a higher pH and more acidic solutions have a lower pH, the pH of 7.0 being neutral. Each whole unit on the scale represents a multiplication factor of 10. Thus, water with a pH of 5.0 is 100 times more acidic than water with a pH of 7.0 (UNEP 2002) and (Mesner, 2005). Water pH is generally not a problem itself, but it is an indicator of other problems such as Sodium and Carbonates. A decrease in pH increases the corrosivity of water, and increasing the pH increases the tendency to precipitate mineral scales such as calcium carbonate ($CaCo_3$).

Irrigation water tends to be alkaline, commonly in the range of pH 7.2 to 8.5. As irrigation water pH increases above 8.2, the potential for sodium problems increases (Ayers and Westcot, 1994). According to Aull *et al* (2005) several factors can be affected by the pH of water, including biological availability and solubility of elements in water. Growth and reproduction of freshwater aquatic species of fish are found to be ideal within a pH range of 6.5 to 8.5; although they may thrive slightly outside this range, pH below 4 or above 10 will kill most aquatic animals (Mesner, 2005).

It seems that Water pH is not a problem by its self but it is closely linked to all biological and chemical processes within a water body as well as processes in water treatment.

2.8.4. Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates (Chapman, 1996). Turbidity in the water is caused by the presence of suspended matter such as clay, silts, finely divided organic and inorganic matter, plankton and other microscopic organisms (AWWA, 1990).

Increases in turbidity have the effect of decreasing the percentage of light transmitted, which results in a decrease in photosynthesis (Lutz, 2004). Suspended particles are often the primary carrier of pollutants to lakes and coastal zones where they settle (UNEP, 2002). Silt and clay fraction (<63µm) is a primary carrier of adsorbed chemicals transported in the water to the watercourses (FAO, 1996). These fine particles are a food source for filter feeders which are part of the food chain, leading to biomagnifications of chemical pollutants in fish and, ultimately, in man (UNEP, 2002). Sources of turbidity in drinking water also include waste discharges, Runoff from watersheds and especially those that are disturbed or eroding, Algae or aquatic weeds and products of their breakdown in water reservoirs. Excessive turbidity in drinking water is aesthetically unappealing, and may also represent a health concern as turbidity can provide food and shelter for pathogens (EPA, 1999). If not removed, turbidity can promote regrowth of pathogens in the distribution system, leading to waterborne disease outbreaks. The NTU of below 5 are required for disinfection; <1 NTU desirable for effective disinfection; >1 NTU may shield some micro-organisms from disinfection (WHO, 2006). According BCWWA (2004) viable coli form bacteria have been detected in waters with turbidity higher than 3 NTU, even in the presence of free chlorine residuals. According to Pernitsky (2003) coagulant doses are generally higher when raw water turbidity increases, although the relationship is not linear. Turbidity puts an excess load on water treatment plants by interfering with disinfection and generating extra sludge (O'Neill *et al.,* 1994).

Turbidity is caused by suspended matter and is aesthetically not pleasing in drinking water. Turbidity interferes with the disinfection of water by shielding micro organisms for effective disinfection NTU levels of below five and greater than 1 are required.

2.8.5. Total dissolved solids

The salts or total dissolved solids (TDS) in irrigation or soil water determine the salinity Grattan (2002). Salinity is stated as TDS in mg/l. It is often determined by measuring the electrical conductivity (EC). In drinking water the palatability of water with a TDS concentration of less than 600mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. No health-based guideline value for TDS has been proposed (WHO, 2006).

TDS is a measure of salinity and directly related to electrical conductivity. Water with salinity levels of 600mg/l are generally considered to be good in quality, however at levels of about 1000mg/l or above become increasingly unpalatable to consumers.

2.8.6. Sodium (Na^+)

All natural waters contain some sodium. Sodium salts are highly soluble in water and it is one of the abundant elements on earth (Chapman, 1996). Increased sodium concentrations in surface water may arise from sewage and industrial effluents. Concentrations of sodium in natural surface waters may vary considerably depending on local geological conditions and waste water discharges. Values can range from 1mg/l or less to 10^5mg/l or more in natural brines (Chapman, 1996).

Sodium in irrigation waters can adversely affect soil structure and reduce the rate at which water moves into and through soils it is also a specific source of damage to fruits (Enderlein and Williams, undated). With drip and furrow irrigation Sodium and chloride injury do not occur in vegetables and row crops unless salinity in irrigation water is severe (Grattan, 2002). According to Ayers and Westcot (1994) overhead sprinkling of sensitive crops can cause toxicities not encountered when irrigating by surface methods. The toxicity occurs due to excess quantities of sodium and chloride from the irrigation water being absorbed through leaves wet by the sprinklers this result in leave burns.

Salts (e.g., sodium chloride) are found in virtually all food and drinking-water. Although concentrations of sodium in potable water are typically less than 20mg/l, they can greatly exceed this in some places (WHO, 2006). The American heart association recommended a drinking water concentration of 20mg/l of sodium (AWWA, 1990). Too much sodium intake in food and water has been identified as a contributor to High Blood Pressure (Michael *et al.*, 2002). The American Heart Association and National Academy of Sciences recommend sodium levels between 500 and 2,400milligrams (mg) per day. However, sodium less than 1800mg is believed to be healthier. No health based guideline sodium concentrations are proposed, however, concentrations in excess of 200mg/l may give rise to unacceptable taste (WHO, 2006).

Sodium occurs naturally in surface water and increase in sodium concentration in water is attributed to geological conditions or waste water discharges. Sodium is responsible for infiltration problems in agriculture and can damage plants during irrigation depending upon the type of irrigation system used.

2.8.7. Calcium (Ca^{2+})

Calcium salts and calcium ions are among the most commonly occurring in nature (Chapman, 1996). They may result from the leaching of soil and other natural sources or may come from artificial sources such as sewage and some industrial wastes. Calcium is usually one of the most important contributors to hardness. Calcium compounds are stable in water when carbon dioxide is present, but its concentration falls when calcium carbonate precipitates due to increase in water temperature, photosynthetic activity and loss of carbon dioxide due to increase in pressure (Chapman, 1996).

Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately (Ayers and Westcot, 1994). According to Grattan (2002) the surface soil aggregates then disperse to much smaller particles which clog soil pores. Calcium concentration in natural waters are typically less than 15mg/l , for waters associated with carbonate-rich rocks concentrations may reach 30-100mg/l (Chapman, 1996). According to the AWWA (1990) even though the human body requires approximately 0.7 to 2.0grams (g) of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones. High concentrations of calcium can also be detrimental to some industrial processes. Calcium is of importance to industry as a component of scale, the scale precipitation of $CaCo_3$ scales on cast-iron and steel pipes helps to inhibit corrosion, but the same precipitate in boilers and heat exchangers adversely affects heat transfers (AWWA, 1990). Thus, both domestic and industrial water users have to consider calcium concentrations.

Calcium is the major contributor to hardness and cause water infiltration problems in irrigation. The calcium concentration in natural waters is typically less than 15mg/l.

2.8.8. Magnesium (mg^{2+})

Magnesium is common in natural waters and along with calcium are the contributors to water hardness (Chapman, 1996). Magnesium arises principally from the weathering of rocks containing Ferro magnesium minerals and from some carbonate rocks. Magnesium metals are not affected by water at room temperature. Magnesium generally is a slow-reacting element, but reactivity increases with oxygen levels. Furthermore, magnesium reacts with water vapour to magnesium hydroxide and hydrogen gas: the chemical reaction that takes place is given in equation 2.

- $Mg\,(s) + 2H_2O\,(g) \rightarrow Mg\,(OH)\,2(aq) + H_2\,(g)$..................................Equation 2

The difference between total hardness and calcium hardness is termed non-calcium hardness. Most of the non-calcium hardness is contributed by magnesium, but salts of aluminum, iron, strontium, manganese, and zinc also are included Lutz (2004). Natural concentration of magnesium in fresh waters may range from 1mg/l to less than 100mg/l, depending on the rock types in the Catchment (Chapman, 1996). WHO does not have recommended levels for magnesium in drinking water. However NAMWATER has a set limit of 200mg/l.

Magnesium and calcium are the main contributors to water hardness and it arises from rock weathering. Natural waters have a concentration of 1mg/l to less than 100mg/l.

2.8.9. Total hardness

Water hardness measures the amount of divalent cations present in water and the capacity of their salts to precipitate soap (Lutz, 2004). Hardness is generally defined as the sum of the polyvalent cations present in the water and expressed as an equivalent quantity of calcium carbonate ($CaCo_3$) (EPA, 1976). The most common such cations are calcium and magnesium (AWWA, 1990). Geographical characteristics of an area determine which ions will be present. Calcium and magnesium are the primary cations in fresh water because of their predominance in sedimentary rocks. According to Chapman (1996) the total content of these salts is known as general hardness, which can be further be divided into carbonate hardness (concentration of calcium and hydro carbonates) and non carbonate hardness (calcium and magnesium salts of strong acids). Hydro carbonates are transformed during the boiling of water into carbonates which usually precipitate out hence the name temporal or remove hardness.

The taste threshold for the calcium ion is in the range of 100–300mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some instances, consumers tolerate water hardness in excess of 500mg/l (WHO, 2006). Depending on the interaction of other factors, such as pH and alkalinity, water with hardness above approximately 200mg/l may cause scale deposition in the treatment works, distribution system and pipe work and tanks within buildings, it will also result in excessive soap consumption and subsequent “scum” formation.

Hardness is principally caused by caused by calcium and magnesium ions in the water and is associated with problems of scale deposition in treatment plants, distribution system and pipes. Water softening is only necessary when hardness exceeds 200mg/l.

2.8.10. Nitrates

Total nitrogen represents the summation of ammonia nitrogen, nitrite plus nitrate nitrogen, and organic nitrogen (Lutz, 2004). Nitrogen in the aquatic environment occurs in four forms: ammonia (NH_3), nitrate (NO_3-), nitrite (NO_2-) and ammonium ion (NH_4+). The conversion of nitrogen from one form to another does not alter the total nitrogen concentration (Lutz, 2004). Nitrate is a final oxidation product of the nitrogen cycle in natural waters and is considered to be the only thermodynamically stable nitrogen compound in aerobic waters (Akoto *et al.*, 2008). Nitrates are an essential component of fertilizers, both man-made and natural (i.e. manure). The mean concentration of nitrate in a typical surface water supply would be around 1mg/l to 2mg/l (AWWA, 1990). In most countries, nitrate levels in drinking water derived from surface water do not exceed 10mg/l, although nitrate levels in well water often exceed 50mg/l (Geo Year Book 2006). The three main sources of nitrate contributions to the environment are as follows: application of manure to grazing and silage fields in livestock production, use of fertilizers in agriculture and deposition of NOx and NHy from atmospheric sources.

Nitrates are necessary nutrients for algae and phytoplankton growth. Discharge of nitrates to surface water bodies greatly accelerates the natural process of Eutrophication (Shao and Wang, 2003). Algal blooms lead to depletion of oxygen levels and generally poor water quality. This leads to fish kills, loss of riparian habitat, death of beneficial aquatic insects, and taste and odour problems and also increases the treatment costs of surface water for municipal consumption. Nitrate in drinking water causes two adverse health effects: induction of methemoglobinemia, especially in infants and the potential formation of carcinogenic nitrosamines (AWWA, 1990). The WHO guideline for nitrate in drinking water is 10mg/l.

Nitrates are an essential component of fertilizers, both man-made and natural, the natural levels of nitrates is around 1mg/l and 2mg/l. Nitrates is responsible for eutrophication in water bodies as well as methemoglobinemia.

2.8.11. Microbial pollution

E. coli provides conclusive evidence of recent faecal pollution and should not be present in drinking-water (WHO, 2006). Freshwater bodies polluted by faecal discharges from man, pets, farm animals and wild animals may transport a variety of pathogens such as bacteria (*Shigella, Salmonella, Cholera Vibrio, and Escherichia*), viruses and protozoans (UNEP, 1998). While E. coli is a useful indicator, it has limitations. Enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of E. coli will not necessarily indicate freedom from these organisms (WHO, 2006). Waterborne transmission of pathogenic E. coli has been well documented for recreational waters and contaminated drinking-water. A well publicized waterborne outbreak of illness caused by E. coli O157:H7 (and Campylobacter jejuni) occurred in the farming community of Walkerton in Ontario, Canada. The outbreak in May 2000 led to 7 deaths and more than 2300 illnesses. The cause of the outbreak was the contamination of the drinking-water supply by cattle excreta (WHO, 2006). The source of drinking water should be protected from animals, and not contaminated by drainage from stock sheds and yards, or septic tank outlets (Lantzke, 2004). Water quality can vary rapidly, and all systems are subject to occasional failure. For example, rainfall can greatly increase the levels of microbial contamination in source waters, and waterborne outbreaks often occur following rainfall. Results of analytical testing must be interpreted taking this into account (WHO, 2006).

E. coli provides conclusive evidence of recent faecal pollution and should not be present in drinking-water. E. coli is a useful indicator but has limitations, enteric viruses and protozoa are more resistant to disinfection; consequently, the absence of E. coli will not necessarily indicate freedom from these organisms.

2.9. Water treatment

The purpose of water treatment is to provide potable water which is chemically and bacteriologically safe for human consumption and has adequate quality for industrial users (John, 1977). Drinking water treatment can range from simple physical treatment and disinfection, to chemical treatment and disinfection, to intensive physical and chemical treatment. Figure 2 shows a process diagram for a conventional water treatment plant. The combination of the first 3 steps primarily removes colloids (including some micro organisms) and natural organic matter (NOM). Step 4 (rapid sand filtration) is a polishing step that removes much of the colloidal material remaining after step 3 (sedimentation).

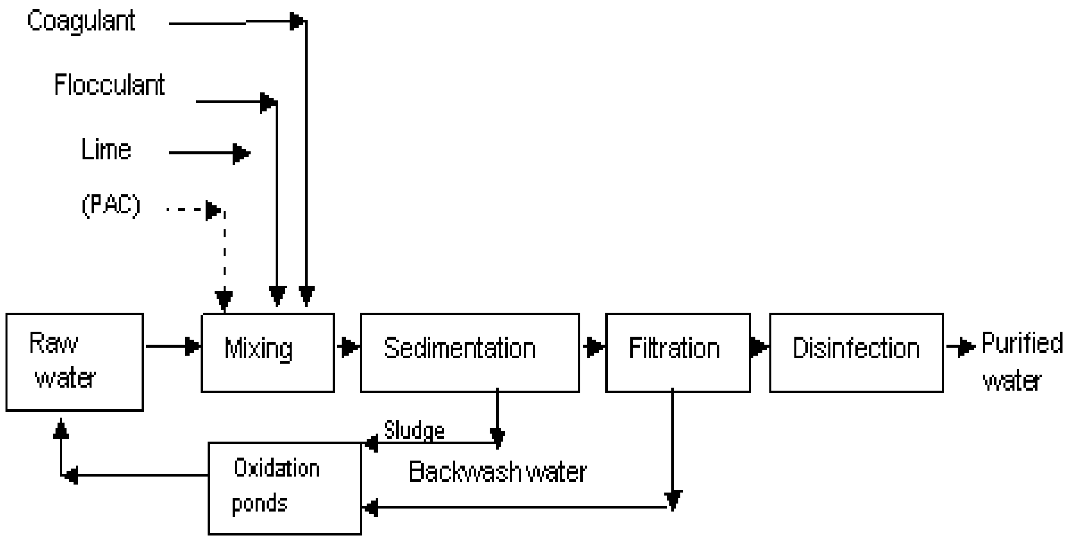

Figure 2: Diagram represents a typical purification plant treating surface water (NAMWATER, 2008).

Countries around the world are making every effort to ensure that the quality of raw water is such that it would only be necessary to use near-natural conditioning processes (such as bank filtration or low-speed sand filtration) and disinfection in order to meet drinking-water standards (Enderlein and Williams, undated). Surface water generally contains a wide variety of colloidal impurities that cause the water to appear turbid. The removal of harmful chemicals and removal turbidity is accomplished through a series of processes referred to as coagulation, flocculation, adsorption and filtration. For water disinfection chlorine is the most widely used as a primary disinfectant and used to provide residual disinfection in the distribution system. A laboratory experiment for the evaluation of coagulation and flocculation of untreated water is called Jar Test. A Jar Test is an experimental method where optimal conditions are determined empirically rather than theoretically. Jar test is meant to mimic the conditions and processes that take place in the coagulation-flocculation clarification portions of water and wastewater treatment plants (Albraham, 2006).

The performance of a treatment unit can affect the efficiency of downstream treatment units. For example, the presence of suspended solids increases the resistance of most microbes to disinfection. Therefore, a failure in the removal efficiency of turbidity or particles by granular filtration processes can decrease the inactivation efficiency of disinfection processes. Similarly, clarification affects filter performance. Clarification removes suspended solids, thus reducing the solid loading to the filters and improving filter performance. If an incorrect dose of coagulant is used and floc is carried over from a sedimentation tank, head loss develops more rapidly, shortening the filter run (WHO, 2004).

It seems that for the treatment process to be effective all the treatment units should be performing effectively.

2.9.1. Coagulation - Flocculation

The coagulation process is commonly included in water treatment plants to promote aggregation of small particles into larger particles that can be subsequently removed by sedimentation and/or filtration (AWWA, 1990). Particles that cause turbidity can be divided by their size, particles larger than 1m (micrometer) will settle in a relatively short time and colloidal (smaller than 1m) do not settle under normal circumstances, colour can also consist of colloidal particles but of a different nature than that of turbidity particles (Seskatchewan environment, 2003). Colloidal particles are classified as hydrophobic (water-hating) and hydrophilic (water- loving). Hydrophobic particles are primarily clay particles; these particles have a negative charge on the particle which repels each other. Hydrophilic particles are primarily organic material, which contribute to colour. These particles have a layer of water molecules around them that keep the particles from bumping into one another and thus growing larger and settling out.

Chemicals, such as aluminum sulphate and ferric chloride, when added to water will combine with alkalinity in the water to form a positive-charged, sticky material (Seskatchewan environment, 2003). If insufficient alkalinity is available, lime or soda ash may have to be added in order for the chemical reaction to take place. This sticky, positive-charged material will decrease the electrical charge on hydrophobic material and, due to its sticky nature, it will speed the process of gathering more and more small particles together. The coagulated particles are then agitated to increase the frequency of collision and cause a grouping of the particles. Small feather-like gelatinous masses will be produced called floc. The mechanical agitation of coagulated particles is called flocculation. The speed and degree of coagulation and flocculation, and the removal of turbidity and colour, is extremely pH sensitive (Heinonen and Lopez, 2007). Metal coagulants are acidic, and a coagulant addition consumes alkalinity. For low alkanity waters, coagulant addition may consume all of the available alkalinity, depressing the pH to values too low for effective treatment. High alkalinity waters (highly buffered) may require high coagulant addition to depress the pH to values favourable for coagulation. The effective pH range for alum coagulation is 5.5 to 8.0 and is preferred in treating water of relative high quality surface waters because it is the chemical needed for coagulation (John, 1977).The only reliable method of determining the proper amounts of chemical agitation and pH is by experimentation, the testing unit for the experimentation is called a jar tester.

The process of coagulation is a chemical process, whereas, the process of flocculation is physical. Coagulation is dependent upon pH, degree of agitation and dosage of chemicals. The only way to determine coagulation dose is by to carrying out a jar test.

2.9.2. Sedimentation

The term clarification, or sedimentation, is normally used to describe the settling of the flocs produced by the coagulation and flocculation process (Ministry of Health, 2005). This is distinct from presettling of highly turbid waters in detention ponds, the water is left undisturbed to allow the heavy clumps of particles and coagulants to settle out.

2.9.3. Filtration

Filtration is the process relied on in most water treatment facilities for the removal of suspended particulate mater (AWWA, 1990). Common particulate removed in water treatment filtration are clay and silt, colloidal and precipitated natural organic matter, metal salt precipitates from coagulation, lime softening precipitates, iron and manganese precipitates and micro organisms. Filtration removes particulate matter that could both increase disinfectant demands and shield organism from disinfection (AWWA, 1990). The rate of filtration directly impacts overall filter performance, efficient backwashing of granular media filters is necessary to maintain optimum filtered water quality.

2.9.4. Disinfection

- *Chlorine*

The primary purpose of disinfecting water supplies is to inactivate microbial pathogens to prevent the spread of waterborne diseases (AWWA, 1990). Waterborne diseases are typically caused by enteric pathogens which belong to the group of organisms transmitted by the faecal-oral route. Disinfection is an effective barrier to many pathogens (especially bacteria) during drinking-water treatment and should be used for surface waters and for groundwater subject to faecal contamination (John, 1977). Residual disinfection is used to provide a partial safeguard against low-level contamination and growth within the distribution system.

Chemical disinfection of a drinking-water supply that is contaminated by faecal matter will reduce the overall risk of disease but may not necessarily render the supply safe. For example, chlorine disinfection of drinking-water has limitations against the protozoan pathogens – in particular *Cryptosporidium* – and some viruses. Disinfection efficacy may also be unsatisfactory against pathogens within flocs or particles, which protect them from disinfectant action (WHO 2004) High levels of turbidity, can protect micro organisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand (O'Neill *et al.*, 1994). Chlorine efficiency is also dependent on pH interactions.

Chlorine is the most widely used primary disinfectant and is also often used to provide residual disinfection in the distribution system. However residual concentrations of chlorine of about 0.6mg/l or more may cause problems of acceptability for some consumers on the basis of taste (WHO 2004).

CHAPTER THREE

3. STUDY AREA

3.1. Natural Characteristics of the North Central Namibia

North Central Namibia is part of the Owambo basin, ancient depression filled with sediments and surrounded by a rim of hills in the south and west (Mendelson *et al.*, 2002). The various depositions that have filled the Owambo basin have produced a very flat landscape.

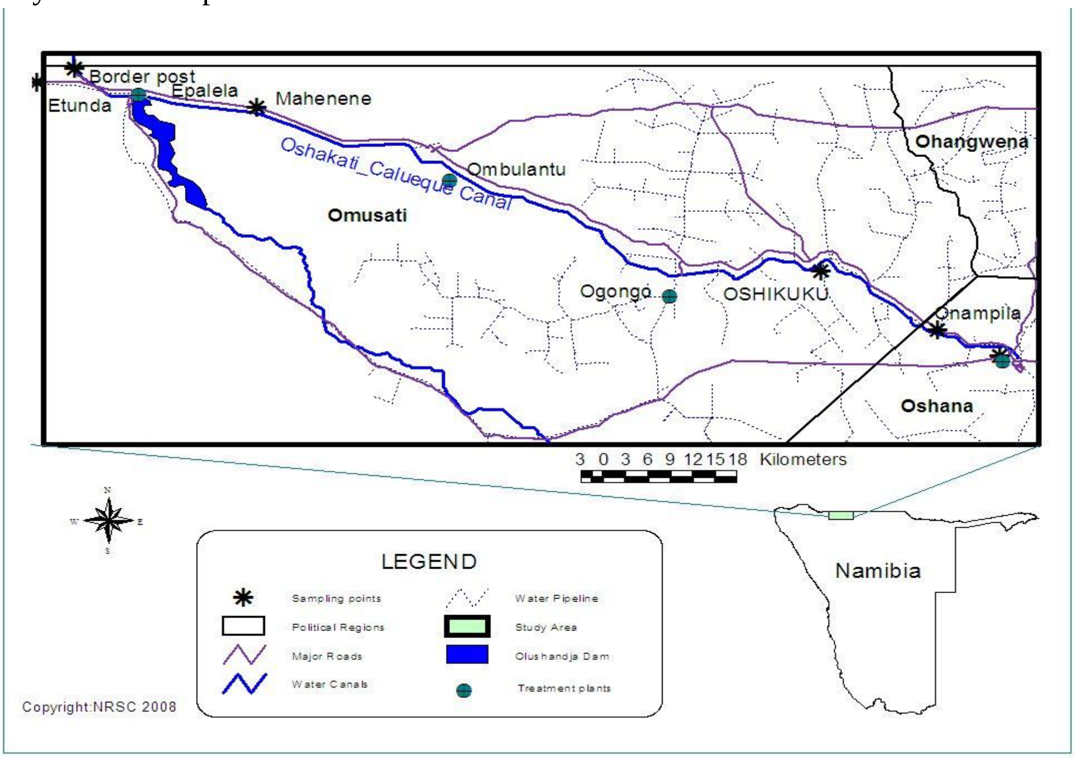

Figure 3: A map of Namibia showing the study area

There are six distinct landscapes in the region, the Cuvelai, the Karstveld, The Salt pans and plains, The Salt pans and plains, the mopane shrub lands, the eastern Kalahari woodlands and the western Kalahari woodlands. The Calueque-Oshakati is located entirely in the Cuvelai Etosha basin. The Cuvelai originates in Angola; its Catchment is falling between those of the Kunene River in the west and Cumbango/Okavango in the east. The system is fed by a number of rivers, some of which have their headwaters as far north as the Encoco highlands in Angola, which receives on average over 800mm of rain a year (Mendelsohn *et al.*, 2000). As the seasonal water move further south the land becomes flatter and the rivers and channels (locally known as Oshanas) meandering towards the Namibian border feed into each other at some places and diverges at other places, forming a massive inland delta which funnel towards Etosha pan.

3.2. Population

The Cuvelai Etosha basin is the most densely populated area of Namibia, with about 800 000 (currently 875701 as projected from 2001 census) people about half of Namibian's total population (Niipele and Klintenberget, 2006). The region has an annual population growth of 2.1 %, (Kluge et al 2006). About 28% of Namibia's total population lives in the Cuvelai drainage area, which comprise just over 1% of Namibian's total area (Central Bureau of Statistics, 2001). The average density in the basin is 40 people per square kilometre, but there are places with densities of 100-300 people per square kilometer in the basin (Mendelsohn *et al.,* 2002).

3.3. Geology

Namibian soils vary a great deal. These variations occur on a broad scale but there is also a high degree of variability at a local level; most areas consist of a mosaic of soil types, usually comprising of one dominant soil that generally covers more than half an area (Mendelsohn *et al.,* 2000). For simplicity it is often best to group areas according to the dominant soils. The geological information of the Catchment area on the Angolan side is hard to find. Geologically the study area belongs to the Kalahari sequence, characterized by up to 500m thick semi- to unconsolidated sediments (Niipele and Klintenberget, 2006). The area is situated in a flat landscape at approximately 1100m above sea level. Soils consist of clayey sodic sands in the lower parts of the landscape and sodic sands on surrounding relatively higher ground (Mendelsohn *et al.,* 2002). The area typically has infertile sandy topsoil, between 0 and 1m thick, underlain by a saline hardpan forming very distinct prismatic structures. The high sodium contents are the result of repeated flooding, when sodium and other salts are carried in by water and then left behind when the water evaporate (Mendelsohn *et al.,* 2002). The clayey sodic sands in the low-lying Oshanas have the highest salt contents. Local floods occur as the water is unable to drain through the hard-pan surface in the Oshanas, the salts in the hard layers dissolve when it rains and move up stream to make the sandy soil even more saline (Mendelsohn *et al.,* 2002).

3.4. Climate

The general climate in the Cuvelai Etosha basin is semi-arid, with the only rains falling from November to April. Rainfall is highly variable in time and space; there is a huge gradient of rainfall across the region. The region have an average annual precipitation of approximately 300mm in the southwest and 550mm in the northeast (Niipele and Klintenberget, 2006) Monthly mean temperature ranges from 26°C in November to 16°C in July. During the coolest period, June to August, the night temperature drops to 7°C while day temperature may reach 40°C (Hutchinson, 1995). Annual potential evaporation is estimated to exceed the annual precipitation by a factor of about five (Mendelsohn *et al.,* 2002).

3.5. Hydrology

The drainage system is characterised by a number of shallow ephemeral watercourses covering an area of about 7,000km² of ephemeral channels (Barnard, 1998). These channels locally known as oshanas, provide an important source of water during the rainfall seasons (Mendelsohn *et al.,* 2000). Seasonal flooding of the oshanas recharges groundwater aquifers in the basin. The degree of recharge depends on intensity, volume and duration of a flood (Hayes *et al.,* 1998). Runoff in the basin is erratic and has been observed to vary from no flows to 0.1km^3/yr as was gauged in 1995 (Kundell, 2007). The Namibian part of the Cuvelai Etosha basin is sub divided into four sub-basins; Tsumeb, Cuvelei-Iishana, Niipele and Klintenberget -Odila and Olushandja.

3.6. Water supply

In the past most people and livestock in central northern Namibia relied on surface water from rainfall during the rainy season, collected in earth dams and in shallow hand dug wells during the dry periods as their main water source (Niipele and Klintenberget, 2006 : Niemann, 1999). Settlement and way of life have for centuries been determined by the access to water. The seasonal in flows Oshanas provide fishing grounds, renew pastures and recharge groundwater supplies. With population expansion, these sources of water could no longer meet the demands and they became increasingly susceptible to pollution and contamination (Mendelsohn *et al.*, 2000). As part of the Water Master Plan of 1974 the Calueque-Oshakati Canal was built to convey water from the Kunene River in southern Angola to the Cuvelai Etosha basin in northern Namibia (Heyns, 2004).

3.7. Calueque–Oshakati Canal

The 154 km long concrete lined Canal was built in the early 1970s in line with the water master plan of 1974 with the last stretch (Ogongo-Oshakati) of the Canal commissioned in 1997. The purpose of the Canal is to transfer raw water from Calueque Dam up to Oshakati purification plant to meet potable, live stock and irrigation demand in the surrounding areas. The raw water is pumped out of the Calueque Dam and discharged into the Caluque oshakati Canal 2.4km downstream of the dam. The Canal was constructed with different cross sections along the route, the capacity of the Canal starts of with $10m^3/s$ and decreases in steps along the rout up to $0.8m^3/s$ (NAMWATER, 2008). There are four treatment plants abstracting water from the Canal, Olushandja, Ombalantu (Ombalantu), Ogongo and Oshakati distributing water to the surrounding villages and urban centres with a network of pipes of about 2600 km in length (Mendelson *et al.*, 2002). Table 1 summarise the water purification processes at the four water treatment plants along the Canal.

Table 1: Characteristics of the four water purification plants along the Canal

	Olushandja	**Ombalantu**	**Ogongo**	**Oshakati**
Capacity	*Slow sand filters 740m3/day *Batch plant 1600m3/day	1584m3/day	36000m3/day	48000m3/day
Water purification process (steps)	*Slow sand filters Pre-treatment sedimentation, mixing, roughing filters, slow sand filters, pH adjustment and Chlorination. *Batch plant Mixing, sedimentation, pH adjustment and Chlorination	Mixing, Sedimentation, Filtration and Chlorination	Pre-Chlorination, Mixing, Sedimentation, Filtration, Post-chlorination and pH adjustment	Pre-Chlorination Mixing, Sedimentation, Filtration, Post-Chlorination and pH adjustment
Chemicals used	Sud-floc, chlorine and lime	Sud-floc, chlorine and lime	Utra-floc, chlorine, and lime	Primco, chlorine and lime

*Mixing is the step were coagulants are added to raw water to form flocs

3.7. Social activities

3.7.1. Fishing

A variety of fish are delivered to the region during the periodic flows in the Oshanas. The amount of available fish is determined by the duration and the intensity of the flood. 17 species of fish were originally recorded in the cuvelai system, mostly Catfish, Barbs and Tilapia. However a further 46 species have been added to the system through the Canal that transport water to towns in north-central Namibian (Mendelson *et al.,* 2002). This fish provide households in the region with a temporal supplement of protein and they are also sold in local markets where they fetch higher prices compared to fish from the ocean thus generating some income for households.

- *Omahene Aquaculture Farms*

The Namibian government is promoting the role of aquaculture to enhance food security, reduce poverty, generate employment, improve rural livelihoods and increase investment (MFMR, 2005). The Omahenene (Onavivi) Inland aquaculture centre in omusati region is a product of the government effort to realize this goal. The farm produces fingerlings and also farm with Oreochromis Andersonii (three spot Tilapia) and Clarias Gariepinus (African cat fish). The fingerlings are sold to small scale fish farmers, in 2005, close to 300 000 fingerlings (tilapia and catfish) were distributed to a total of 191 small scale fish farmers compared to the previous year, where only 90 000 fingerlings were distributed (MFMR, 2005). The farm abstracts its water from the Calueque-Oshakati Canal.

3.7.2. Farming

The communal sector, mainly in the North, supports around 140 000 families (FAO, 2005). Agriculture is the most important provider of livelihood in the Cuvelai Etosha basin but it is also the activity that puts most pressure on the basin's natural resources. Even though many rural households derive their income from a variety of sources almost all the estimated 85 000 households in the region are surrounded by fields for farming (Mendelson *et al.,* 2002). Generally, agricultural productivity is low because of lack of irrigation, lack of appropriate farming methods and other inputs (FAO, 2005). Farmers in communal areas engage in rain fed crop and livestock production, making the sector vulnerable to climatic variability, which is reflected in the high variability of output from one year to another; the sector is further constrained by poor marketing initiatives. Mahangu (pearl millet) and sorghum is the most important crop, while livestock livestock numbers are dominated by cattle, goats, donkeys and poultry.

- *Etunda Irrigation Scheme*

Namibia is endowed with some rich natural resources such as diamonds and other mining products, fish and outstanding tourist attractions. This has led to a relatively high per-capita income that classifies Namibia as a low middle-income country. However, there is such a skewed distribution of wealth and poverty, as 10% of the society receives 65% of the income, while 90% of the society receives the remaining 35% of the income (African development bank, 2004). In Namibia, a household is classified as relatively poor if it devotes over 60% of its expenditure to food and extremely poor if it devotes over 80% of its expenditure to food. Using this classification, 47% of Namibia's households were relatively poor and 13% extremely poor according to the National (African development bank, 2004). Government embarks on a programme of increasing crop production by expanding the areas under irrigation. Such a development would contribute significantly to employment creation, attract some population to rural areas, provide livelihood and reduce poverty to an increasing number of the unemployed. Etunda Irrigation Project abstracting water from the Calueque Canal became operational in 1995/96, and has about 640 ha under irrigation (FAO, 2005). A total of 87 families are currently settled (phases 1 & 2), with 16 more envisaged for 2008 (National planning commission (NPC), 2008). The farmers produce maize, wheat, vegetables, groundnuts, watermelon, butternuts, potatoes and bananas. Currently the project has a permanent staff component of 22 and they employed during the period April 2004 to March 2005 1,374 temporary staff (NPC, 2008).The scheme make use of the center pivot irrigation system.

CHAPTER FOUR

4. MATERIALS AND METHODS

4.1. Study design

The sampling sites were chosen to reflect on different activities along the Canal that could be affected by the change in water quality; The Omahenene Border Post (OBP) was used as a control point as it is furthest upstream and is the point where the Canal enters Namibia. The Etunda Irrigation Scheme (EIS) the abstraction point of the irrigation scheme was used to collect water samples to determine water suitability for irrigation use. Omahenene Aquaculture Farms (OAF) the abstraction point of the aquaculture farms was used to collect water samples to determine the water suitability for aquaculture use and Oshakati Water Treatment Plant (OWTP) is the furthest upstream the Canal it was used to determine the extent of pollution in the Canal by comparing the parameter's values with those obtained at OBP. Figure 4 show the 4 sampling locations (OBP, EIS, OAF and OWTP) along the Canal were water samples to determine suitability for various uses were collected. The location of the treatment plants along the Canal is also shown (TP1, TP2, TP3 and TP4).

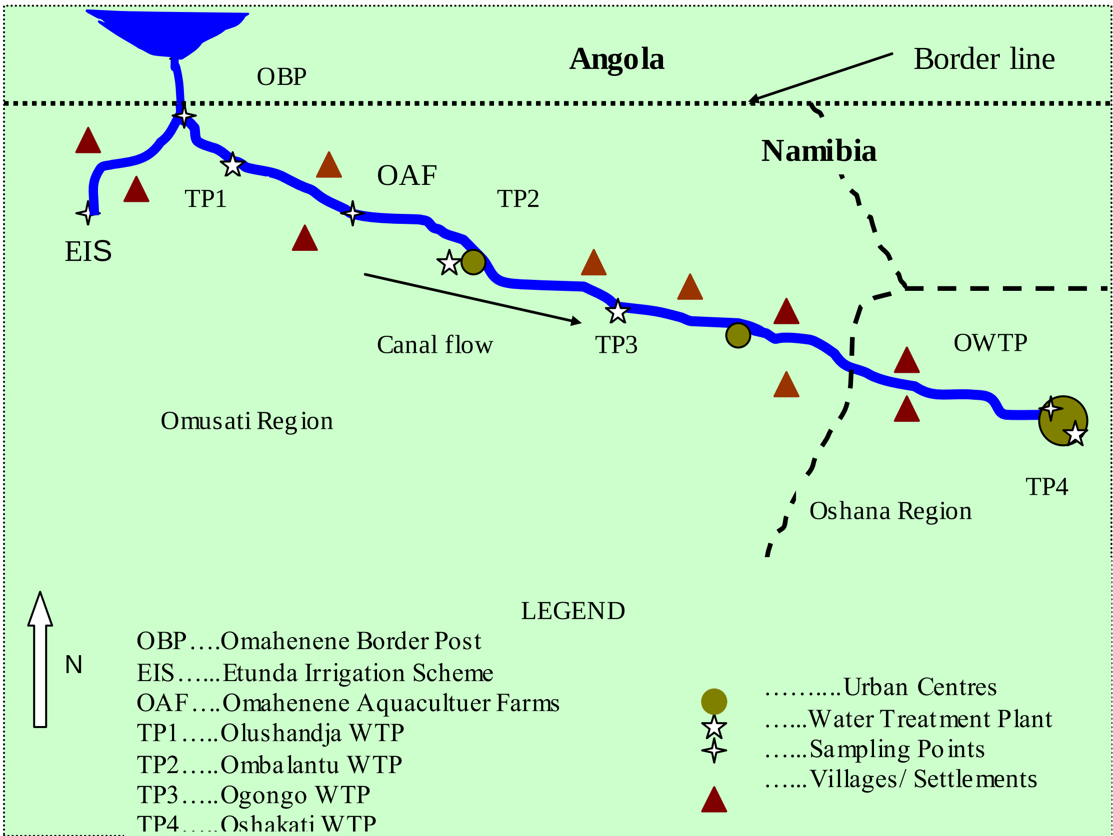

Figure 4: A map showing the Canal, sampling sites and the water treatment plants

4.2. Selection of water quality parameters

The following parameters were determined: Turbidity, Temperature, pH, Dissolved oxygen, Nitrate, Sodium, Magnesium, Calcium, Total Dissolved solids and E.coli. They were compared to NAMWATER standards given in Table 1B, 2B and 3B in

Appendix B, WHO guidelines for drinking water (2006) and other generally accepted standards and guidelines to determine the water suitability for various uses. In general, the selection of parameters for monitoring is based on their indicative character (for uses/functioning and impacts on the various ues), their occurrence and their hazardous character. Turbidity is an indirect measure of total suspended solids (TSS) is comprised of organic and mineral particles that are transported in the water column and these are closely linked to erosion. Turbid waters are aesthetically unappealing to consumers and impact on water treatment as it increases the amount of chemical used to purify the water increase with turbidity.

Changes in temperature largely affect the biological and chemical characteristics of water; overall increase in temperatures in water bodies can cause increased chemical and biological reaction rates, mineral solubility, and growth of aquatic organisms. Dissolved oxygen (DO) determines the health of the aquatic environments by determining which animal species can thrive in it; it is also a good indicator of micro biological activity in the water as low DO levels indicate high biological demand which is linked to polluted waters.

The water pH is closely linked to biological productivity in aquatic systems and is an important factor in water treatment as coagulation and flocculation processes are extremely pH sensitive. The potential health risk of nitrate in water has led to increased stringency in nitrate monitoring of waters because it can be reduced to nitrite which has been linked to Methamoglobinemia in infants and pregnant woman (Fatoki *et al.,* 2001).

TDS were determined because it determines the salinity of water, which is an important measure in determining water suitability for irrigation use. Sodium, Calcium and Magnesium were used to calculate the Sodium Absorption Ratio (SAR) a measure used to determine water suitability for irrigation in terms of soil structure stability. Hardness was determined due to its effects on water treatment, agriculture and domestic use related problems it poses. Major factors affecting microbiological quality of surface waters are discharges of sewage and runoff from settlements, the presence of E.coli in the water confirms recent pollution by faecal material of man or other animals. The author acknowledges that BOD is a critical parameter in determining water pollution. According to Davis, R., and Hirji, R., (2003) BOD, nutrients, heavy metals and industrial chemicals are usually measured in point source pollution, since the pollution getting into the Canal are from diffuse sources BOD was not considered critical in this study.

4.3. Time and frequency of sampling

Sampling was carried out twice a month; it started at about 07:00: AM local time at the Omahenene Border Post and at about 08:30: AM at the Etunda Irrigation Scheme, at about 10:00: AM and at about 15:30 PM at the Oshakati Water Treatment Plant. Samples at respective station were collected approximately at the same times of the day on all sampling campaigns.

4.4. Data Collection

4.4.1. Suitability for various uses.

The location of the four selected sites along the Canal is shown in Figure 4. Grab samples were collected on five occasions at all sampling stations on: 6 February 2008, 26 February 2008, 11 March 2008, 31 March 2008 and 14 April 2008. The sampling depth was not of importance since shallow lakes (<5 m) and shallow flowing rivers do not generally exhibit any sort of recognisable chemical stratification (Germs *et al.*, 2004). Water samples were collected in 500ml water bottles, prior to sampling containers were washed with detergent and then rinsed using tap water. During sampling the bottles were rinsed three times with the water to be sampled before being filled with the water. Sampling bottles were labelled soon after sampling with station number, date of sample collection and any other comments of interest were recorded and samples immediately placed on ice in a cooler box. Appendix C shows the form used in the field during data collection.

Samples for microbiological tests where collected in sterile grass bottles. The caps of the bottles were replaced when the bottle was submerged under the water, special care was exercised to avoid cross contamination. The bottles were not overfilled; a space was left to allow mixing of the sample. The samples were then place on ice in a cooler box and were immediately transported to the laboratory in a cooler box stacked with ice. The methods used for analysis of various parameters are summarised in Table 2.

Table 2: **Analytical methods used to determine parameters.**

DETERMINANT	INSTRUMENT	METHOD
pH (25 °C	Electrode Crison - 1985	pH electrode
Conductivity	Crison Micro CN 2200	Conductivity probe
Sodium;Potassium; Calcium; Magnesium + Heavy metals (Fe,Mn,Cd,Cu,Pb,Zn)	Perkin Elmer Optima	Inductively Coupled Plasma / ICP
Nitrite	Skalar San Plus	Automatic analyser - Colorimetric, automated
Turbidity	Hach 2100AN Turbidity meter	Nepfelometric method
Dissolved Oxygen in mg/l O_2	WTW Electrode	DO probe
Total Nitrogen	Colorimetric	

Note: All analysis were in accordance with APHA (2000)

The enumeration of Escheria coli (E. coli) was done in accordance with the standard fermentation technique at the presumptive phase of 24-48 hours at temperatures between 37-44 °C (APHA, 2000).

- *Data quality control*

The mean and standard deviation for the various measured parameters were calculated and validated by comparison with literature to identify values that were outside the normal range of the respective parameters.

4.4.2. Pollution load

Pollution load was determined in accordance with UN/ECE (2000) which outlined the three basic steps for estimating pollutant load as follows: Measuring water discharge, Canal discharge was determined by placing a floating object in the water at a known distance and the time for the object to travel between the two points recorded this was carried out six times and the average used to compute the discharge by multiplying with the area.

- Measuring water discharge (e.g., m^3/s)
- Measuring pollutant concentration (e.g., mg/l) and
- Calculating pollutant loads (multiplying discharge multiplying concentration over the time frame of interest).

Stream flow was determined by velocity-area approach as described by Sullivan (2007) and Water Action Volunteers (2002). First the width of the stream is measured, and then average water depth is determined by measuring at a number of locations across the width to find the average depth of site. The cross-sectional area (m^2) of the stream is obtained by multiplying the average depth by the width. Water velocity (m/s) is determined by the number of seconds it takes a float to travel along the length of stream being studied. The formula used to calculate stream flow is given in equation 3.

Stream Flow = Area x Velocity…………………………………………..Equation 3

The pollution loads in kg per day (kg/day) of all sampled parameter were calculated using equation 4 And Equation 5 was used to compute total pollution load between February and April 2008.

$$P_L = Q * C \quad \text{...Equation 4}$$

Where P_L= pollution load

Q= Canal discharge (m^3/day)
C= Concentration (kg/ m^3)

$$P_{TL} = Q*(C_1 + C_2 + C_3 \cdots\cdots C_n) \quad \text{...Equation 5}$$

Where P_{TL}= Total pollution load (kg/day)
$C_1+C_2+C_3$= Concentrations of each parameter (kg/ m^3)

4.4.3. Impact of pollution on water treatment

Water treatment plant performance data for various water treatment plants were obtained from NAMWATER which contained monthly average values of turbidity, pH, coagulants and disinfectant (chlorine) used and cost of chemicals used. Appendix D presents the data obtained from NAMWATER. To confirm the impacts of pollution on the water treatment process, jar tests were carried out on water samples collected at the four treatment plants using the same water purification chemical. Direct observation and unstructured questioners to key personnel were used to gain further information on the impacts of pollution on the water treatment process.

4.4.4. Intervention measures

To develop intervention measures available literature on pollution control were reviewed and representative sites where chosen (down stream a village, small town and major town) along the Canal were the type and amount of litters collecting in the Canal were determined twice a month from February to March 2008. Appendix E is the form used in the field during data collection.

CHAPTER FIVE

5. RESULTS AND DISCUSSION

5.1. Suitability of water for various uses

Physical and chemical parameters were measured to establish the extent of water pollution in the Canal and determine how it affects the water quality suitability for various uses. The parameters examined during the study were pH, turbidity, dissolved oxygen, temperature, magnesium, sodium, calcium, Nitrate, E. coli, total hardness and total dissolved solids. Table 3 and Table 4 represent the summary of the obtained results at the four sampling stations. Figures from 4 to 15 present the variations of the different parameters at sampling stations on the dates of sampling.

Table 3: The summary of parameters which affects agricultural water use (range, mean and standard deviation of the five data set (n=5)) at the four stations between February and April 2008.

Stations	pH	Sodium (mg/l) as CaCo3	Calcium (mg/l) as CaCo3	Magnesium (mg/l) as CaCo3	TH (mg/l) as CaCo3	TDS (mg/l)
OBP	6.3-7.5 (6.9±0.5)	3-6 (5±1.3)	8-15 (10±3)	4-8(5±2)	12-23 (15±5)	38-48 (43±4)
EIS	6.9-7.8 (7.4±0.4)	3-7 (5±1.6)	8-18 (11±4)	4-8(6±2)	12-26 (17-6)	36-48 (44±5)
OAF	7-7.9 (7.6±0.4)	ns	ns	ns	ns	52-82 (60±12)
OWTP	6.4-7.6 (7.2±0.5)	8-21 (14±5)	8-16 (13±3)	4-21(12±7)	12-33 (24±9)	41-86 (68±20)

**ns Not sampled *TH Total Hardness * TDS Total Dissolved Solids*
**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

Table 4: The summary of physical, gases and biological parameters (range, mean and standard deviation of the five data set (n=5)) at the four stations between February and April 2008.

Stations	Temperature (°c)	Turbidity (NTU)	Nitrate (mg/l)	DO (mg/l)	E. coli (MPN/100ml)
OBP	23.6-25 (24±0.6)	29-253 (111±86)	<0.1	4-5 (4.4±0.4)	5-10(4±3)
EIS	25-25.5 (25.3±0.2)	35-293 (133±101)	<0.1	3.3-4.5 (3.9±0.5)	14-21(17±3)
OAF	25.7-27.8 (26.7±0.1)	85-423 (205±134)	<0.1	4.2-5.1 (4.7±0.4)	24-33(28±4)
OWTP	25-26 (25.6±0.4)	210-284 (243±32)	<0.1	3.5-5 (4.5±0.6)	37-45(42±3)

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant
* Nitrate values were all given as less than 0.1 (no specific number given)

5.1.1. Suitability of Canal water Temperature for various uses

The summary of the temperature results at the four sampling stations is presented in Table 4. The average temperatures at the four sampling points were about 25ºC. There was a variation in temperature values at the different stations which could be attributed to the prevailing environmental conditions such as atmospheric temperature, cloud cover, rainfall and wind conditions at the time of sampling. Figure 5 presents temperatures variation at different sampling stations from February to April 2008.

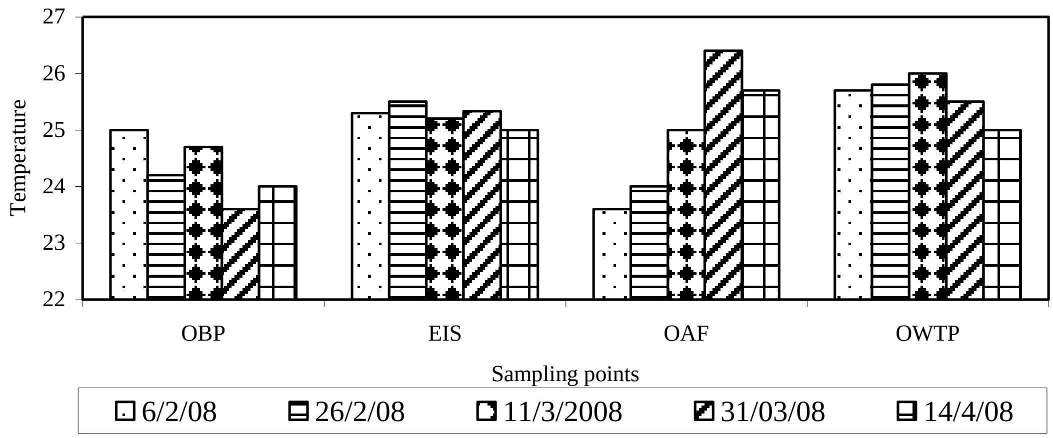

Figure 5: Temperature variations at sampling sites for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

Compared to a similar study by Olajire and Imeokparia (2000) on the Osun Rivers in Nigeria, the water temperature in the Canal was lower than those recorded in Osun River which averaged at 28 °C. It was going to add more value to the thesis if baseline conditions before Canal was built were found for all the measured parameters in order to make comparison, but they proved hard to find.

- *Suitability of Canal water temperature for agricultural use*

The rates of chemical reactions tend to double for each every 10°C rise in temperature (AWWA, 1990). One of the chemical reactions significantly affected by temperature is the dissolving of $CaCo_3$, in water as less $CaCo_3$ dissolve at higher temperatures and this excessive precipitate clog water lines pipes. Temperature also plays a part in the algal growth that cause clogging of water pipes and eutrophication of irrigation Canals.

The water quality in the Canal was considered suitable for agricultural use in terms of temperature as it was with in the normal range of natural surface water suggested by chapman (1996) of between 0-30ºC.

- *Suitability of Canal water temperature for fisheries*

According to UNEP (2006) temperature affects the rate of chemical reactions, the rate at which algae and aquatic plants photosynthesize, the metabolic rate of other organisms, as well as how pollutants, parasites, and other pathogens interact with aquatic residents. The rate of metabolism in pikilothermic animals depends upon temperature (Alabaster *et al.,* 1982). Temperature influences the solubility of dissolved oxygen (DO) and other materials in the water column (e.g., ammonia) which are all critical to the survival of fish. The temperature ranges of surface waters range from 0- 30ºC and hot springs can reach 40ºC (Chapman, 1996). For fish survival, in a warm water stream temperatures should not exceed 31.6ºC and cold water streams should not exceed 20ºC (SEED, 2003).

The water in the Canal was be considered suitable for fisheries in terms of temperature ranges as they were all with in the acceptable ranges that can support fisheries and other aquatic life forms as suggested by SEED (2003).

- *Suitability of Canal water temperature for potable use*

According to WHO guidelines for drinking water, cool water is generally more palatable than warm water, and temperature will impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. Elevated water temperature enhances the growth of micro organisms and may increase taste, odour, colour and corrosion problems (WHO, 2006).

Water in the Canal was considered suitable for potable use in terms of temperatures as it was within the general temperature ranges of surface water 0- 30ºC referred to earlier. There is no set temperature threshold of water preference for human but ''cooler'' water is acceptable and there is no set temperature range considered cool.

5.1.2. Suitability of Canal water Dissolved oxygen (DO) content for various uses

The summary of DO concentrations at the four sampling stations is presented in Table 4. The dissolved oxygen concentration at all sampling points averaged 4.3mg/l at average temperatures of about 25ºC. Dissolved oxygen concentration showed variations at the different points along the Canal; this can be attributed to turbulence, temperatures, and atmospheric pressure and/or biological activities at the various points along the Canal, as suggested by Chapman (1996). Figure 6 illustrates the DO variations at four sampling stations along the Canal from February to April 2008.

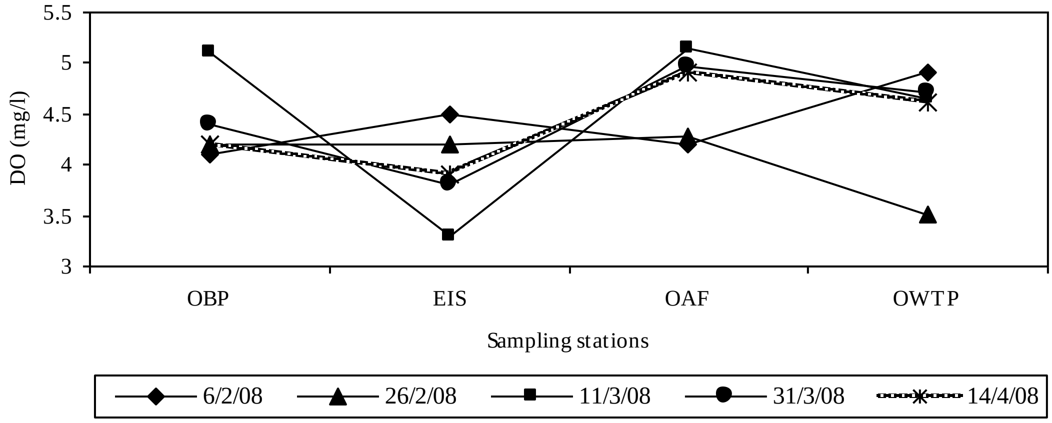

Figure 6: DO variations at sampling sites for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

- *Suitability of Canal water DO concentrations for agricultural use*

DO is not one of the a critical parameter in determining water suitability for agricultural use, suggested by Hopkins, *et al.* (2007) , however DO levels influence the rate at which aquatic plants grow, which have implications on agricultural operations, such as clogging of pipes and eutrophication of irrigation Canals.

- *Suitability of Canal water DO concentrations for fisheries*

Dissolved oxygen (DO) is a measurement of the amount of oxygen gas dissolved in water, and available for use by plant and aquatic species (WHO, 2006). Oxygen concentration in natural running waters should be close to 100% saturation, that is, between 9mg/l and 11mg/l depending on temperature while concentration in unpolluted waters is usually close to but less than 10mg/l (Chapman, 1996). Dissolved oxygen (DO) is a critical water quality parameter for characterizing the health of an aquatic system (SEED, 2003). Elevated temperatures decrease gas solubility and respiration rates, warmer waters have less oxygen solubility (Aull, 2005). The one day minimum for cold-water species is 5mg/l in early development stages and 4mg/l for other life stages. For warm water species, 5mg/l is needed in early stages and 3mg/l for the other life stages (Aull, 2005: Hammer *et al.,* 2001).

The water in the Canal was considered suitable for fisheries in terms of DO. The Omahenene Aquaculture farm farms with Clarias Gariepinus (African cat fish) which requires between 3-5mg/l of DO during their fingerlings and adult life stages (FAO, 2007). These levels are well within the average recorded DO concentration at all the sampling stations. However for the advanced fry stage African cat fish requires about 80-100% saturation (FAO, 2007). The average measured DO concentration at all sampling points was not sufficient and other precautions such as aeration have to be employed to increase the DO concentrations. Compared to a similar study done by Birungi *et al.* (2007) in Uganda on the Nile tilapia the site that recorded the highest number of fish kills had DO levels of 0.54mg/l which were lower compared to the average ranges of 4.3 found in the Canal. DO concentrations in the Canal were unlikely to cause adult fish mortalities and but could however lead to fish kills in the advance fry stage.

5.1.3. Suitability of Canal water pH for various uses

The summary of pH results at the four sampling stations is presented in Table 3. The average pH values at all sampling points ranged from 6.9 to 7.6, these values are well within the NAMWATER standard (6-9), as well as Canadian standards (6-9) and the WHO guidelines (6.5-9.5). The pH values showed variations at the different sampling stations along the Canal and this could be attributed to the prevailing rains on the days samples were collected. Figure 7 presents pH variation at each sampling station compared to NAMWATER standards (Class A) for potable use and accepted ranges for agricultural and fisheries use from February to April 2008.

The pH values in the Canal were comparable to studies done on rivers in the SADC, for example a study by Germs *et al* (2004) on the Chinus River in South African recorded pH values in the range of 8.1-8.6 and a study by Sajidu et al (2007) on streams in Malawi found pH ranges of 6.63-9.38. However studies on the Likangala River in Malawi by Chimwanza *et al* (2005) and Brong Ahafo regions in Ghana by Akoto and Adiyiah (2007) found pH ranges of 5.8 - 6.9. And 5.47-7.54 respectively which had lower pH ranges compared to the Canal water which was 6.9-7.6. The studies on Likangala and Brong Ahafo had lower pH values which were outside the (6-9) which WHO recommends for drinking water.

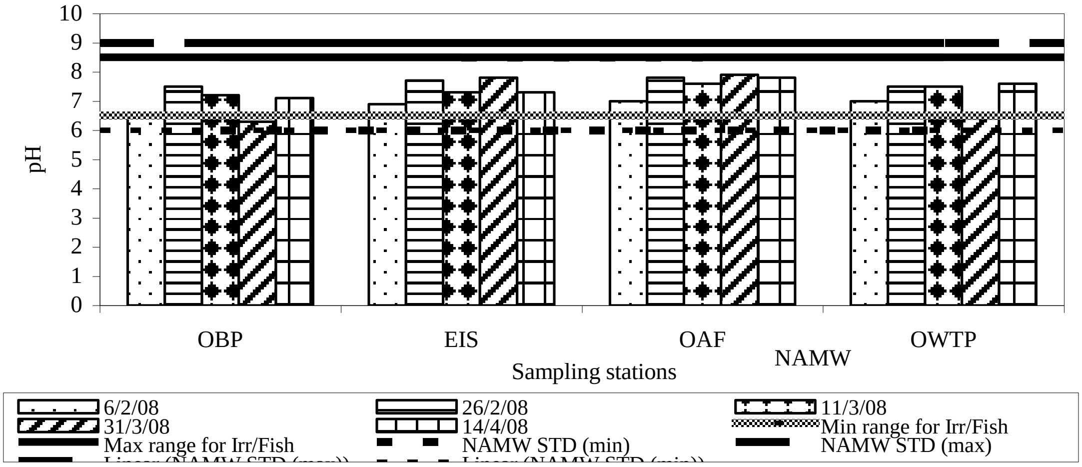

Figure 7: pH variations at sampling sites compared to various standards for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

- *Suitability of Canal water pH for agricultural use*

Water pH is an indicator of the acidity or basicity of water, but is seldom a problem by itself, the main use of pH in a water analysis is for detecting abnormality of the water (Ayers and Westcot, 1994). The normal pH range for irrigation water is from 6.5 to 8.4 (Ayers and Westcot, 1994). An abnormal value is a warning that the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion (Ayers and Westcot, 1994). Low salinity water (TDS <128mg/l) sometimes has a pH outside the normal range since it has a very limited buffering capacity, this water is very corrosive and may rapidly corrode pipelines, sprinklers and control equipment.

The Canal water was considered suitable for agriculture since the average pH values were within the considered normal pH range suggested by Ayers and Westcot (1994). The Canal water did not pose a danger of nutrient imbalance associated with abnormal pH. However the water in the Canal has low salinity (TDS < 128mg/l) could at times contribute to abnormal pH values due to its limited buffering capacity. Similar studies by Germs *et al* (2004) on the Chinus River in South African and Sajidu *et al* (2007) on streams in Malawi at comparable pH values did not report any agricultural water quality problems related to pH. Even similar studies by Chimwanza *et al* (2005) on Likangala River in Malawi and Brong Ahafo regions in Ghana by Akoto and Adiyiah (2007) which recorded lower pH values compared to the Canal did not report any agricultural problems related to water pH. It was going to add more value to the thesis if baseline conditions before Canal was built were found for comparison sake, but it proved hard to find.

- *Suitability of Canal water pH for fisheries*

Natural fresh waters have a pH ranging from 4.0 to 10, The pH of most productive natural waters that are unaffected by pollution is normally in the range of 6.5 to 8.5 at sunrise, typically closer to 7 than 8 (Robert, undated). According to Mesner *et al* (2005) the growth and reproduction of freshwater aquatic species of fish are found to be ideal within a pH range of 6.5 to 8.5; although they may thrive slightly outside this range, pH values of below 4 and above 10 will kill most fish species and very few animals can tolerate waters with a pH below 3 or above 11 (Mesner *et al.,* 2005). Although the tolerance of individual species varies, pH values between 6.5 and 8.5 usually indicate good water quality (UNEP, 2006). This pH range can be extended beyond the lower limit by the direct discharge of acid effluents or secondary effect, following rainfalls or from mine drainage. Rivers and lakes may be made more alkaline by either the direct discharge of wastes or as secondary effects of vigorous photosynthetic activity by aquatic plants. Acidic water cannot support the growth of phytoplankton, zooplankton and diterious bacteria which are all important in providing an environment conducive for fish growth (Birungi *et al.,* 2007)

The water in the Canal was suitable for fisheries in terms of pH as the average pH values from all the sampling stations were within the ideal range that supports the growth and reproduction of freshwater aquatic fish species of fish suggested by (UNEP, 2006). The pH values were not acidic, as a result can support the growth of phytoplankton, zooplankton and diterious bacteria which are important for fish growth. The pH values at all sampling stations meet the pH range requirement for Oreochromis Andersonii which is farmed at Omahenene Aquaculture Farms . Since similar studies in the region with comparable pH ranges referred to earlier did not experience fish mortality the water in the Canal were unlikely to cause fish mortality related to pH concentrations.

- *Suitability of Canal water pH for potable use*

Generally a decrease of one full unit represents an increase in acidity of ten times (UNEP 2002). Natural fresh waters have a pH that range from 4.0 to 10 and unpolluted waters have pH of 6.5 to 8.5 (Robert, undated). When pH is below 6.5, corrosion effects may become significant while the frequency of incrustation and scaling problems may be increased with pH values greater than 8.5 (WHO, 2006). According to WHO (2006) for effective disinfection with chlorine, the pH should preferably be less than 8.

In terms of pH, the water quality in the Canal was suitable for potable use, as its pH values meet the NAMWATER standard as well as the WHO guidelines for drinking water. The pH range was also within preferred range for effective disinfection with chlorine which was the disinfectant used at the treatment plants purifying water from the Canal. Similar comparable studies earlier pointed out found that the pH levels were also within acceptable levels for human consumption.

5.1.4. Suitability of Canal water Turbidity for various uses

The summary of the turbidity results at the four sampling stations is presented in Table 4. The average NTU values ranged from 111 to 243. The average values where higher at the OWTP which is the furthest down stream and lowest at OBP which is the furthest upstream the Canal, there is generally an increase in turbidity from upstream to down stream. The variation in turbidity can be attributed to the prevailing environmental conditions such as rain that was experience prior and on dates of sampling (26/2/08, 11/3/08 and 31/3/08). According to UNEP (2002) overland flow carries suspended solids into water courses and thus increasing turbidity. The increasing trend in turbidity from upstream to downstream the Canal can be attributed to the cumulative effect of overland flow into the Canal. Figure 8 presents the variation in NTU values at different sampling stations along the Canal from February to April 2008.

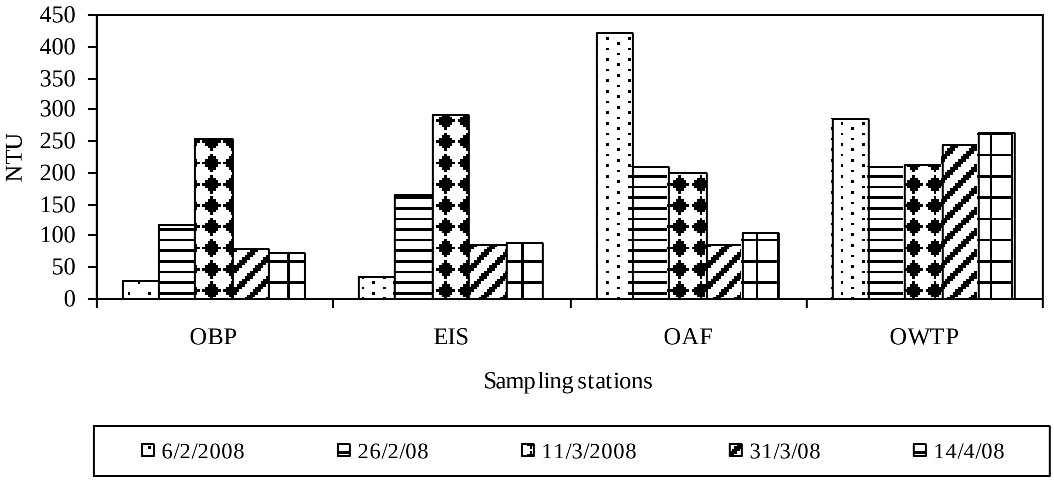

Figure 8: Turbidity variation at sampling sites for February to April 2008
**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

The turbidity values in the Canal were lower than levels found in a similar study by Fatoki *et al* (2001) on the Umtata River in South Africa which recorded NTU values of 1899. However the turbidity in the Canal were found to be higher than those from similar studies on the Isinuka River in South Africa by Faniran and Adeleke (2001) and Brong Ahafo regions in Ghana by Akoto and Adiyiah (2007) which averaged NTU values of 43.03 and 72 respectively. These studies found a general increase in turbidity from upstream to down stream which is similar to the trends in the Canal.

- *Suitability of Canal water turbidity for agricultural use*

Suspended materials are the cause of turbidity in the water, which are the chief cause of clogging in Sprinkler irrigation systems (Chapman, 1996). Suspended particles consist of soil particles of different sizes, lime carbonates, solid material washed into Canals, algae, and eroded material from reservoirs. Particles heavier than water can be filtered or settled out (Ayers and Westcot, 1994). Screening is the method used to prevent clogging but is not effective in all cases, as small particles may still get through the screens.

Clogging is the main water quality related problem experienced at the Etunda Irrigation Scheme abstracting water from the Canal and using center pivot system for irrigation. The scheme filters the water at the point of abstraction, however small particles still get through the screens and clog the irrigation system. This according to the farm manager contributes to reduced yield as some plants do not receive adequate water due to partially or fully blocked spraying units. The times spend on unblocking the irrigation system also limit the time available for irrigation. The manager noted that with the reduction in the amount of suspended solids in water, would increase their production yield by at least 10%.

The water quality in the Canal in terms of turbidity was considered unsuitable for irrigation with the Center Pivot Irrigation System, as it had suspended materials that caused clogging of the irrigation system at Etunda Irrigation Scheme and lead to a reduction in production yield and increasing labour cost. The study also found that suspended materials at times lead to the siltation of the Canal and this reduced water flows to the irrigation scheme.

- *Suitability of Canal water turbidity for fisheries*

Some substances that cause turbidity are more desirable in fish culture or recreational farm ponds than others (Hargreaves, 1999). In moderate amounts, phytoplankton is a desirable form of turbidity because it provides food for microscopic animals (zooplankton) and filter-feeding fish, and improves water quality by producing dissolved oxygen and removing potentially toxic compounds such as ammonia. On the other hand, turbidity caused by clay particles is generally undesirable because it keeps light from penetrating the water, and light is required for algal growth. At very elevated concentrations, clay particles can also clog fish gills or smother fish eggs. In the wild high turbidity can affect fish populations by decreasing habitat, by reducing growth through a reduction in food supply or feeding ability, and by disrupting migrations through avoidance (Rowe and Dean, 1997). A study by Alabaster *et al* (1982) found that most fish species such as common carp endured maximum turbidities of 100000NTU for up to a week or more and some tropical fish species can survive turbidity of 6000 NTU and killed by turbidity values above 40 000NTU.

The water in the Canal was considered suitable for fisheries use as fish are able to survive in higher turbidity than the once recorded in the Canal. Compared to similar study in the Region by Fatoki *et al* (2001) on the Umtata River in South Africa which recorded high turbidity (1899NTU) but was able to support fisheries it can therefore be concluded that the water in the Canal is suitable for supporting fisheries on this basis as it recorded lower turbidities highest of 243NTU.

- *Suitability of Canal water turbidity for potable use*

Many countries make every effort to ensure that the quality of raw water is such that it would only be necessary to use near-natural conditioning processes (such as bank filtration or low-speed sand filtration) and disinfection in order to meet drinking-water standards (Enderlein and Williams, undated). Generally turbidity affects the aesthetic quality of water (WHO, 2006). The amount of chlorine required for disinfection also increases with increases in turbidity (NAMWATER, 2008) as high levels of turbidity, can protect micro organisms from the effects of disinfection, stimulate the growth of bacteria and give rise to a significant chlorine demand (O'Neill *et al.*, 1994). Periodic high turbidity in source water can overcome the treatment processes allowing enteric pathogens into treated water and the distribution system (WHO, 2006). According to WHO guidelines NTU value of between 1NTU and 5NTU is desirable for effective disinfection; NTU of less than 1 is undesirable as it may shield some micro-organisms from disinfection (WHO 2006). According BCWWA (2004) viable coli form bacteria have been detected in waters with turbidity higher than 3NTU, even in the presence of free chlorine residuals.

The water quality in the Canal was not fit for direct human consumption prior water treatment is required before use for domestic purposes. The levels of turbidity in the water require full conventional treatment process to purify the water to the required levels for human consumption this has implication on the cost of purifying water as more chemicals are required for water treatment especially chlorine disinfectant which increase with increase in turbidity.

5.1.5. Suitability of Canal water Total dissolved solids for various uses

The summary of TDS concentration all at the four sampling stations are presented in Table 3. The average values from the four sampling points ranged from 43mg/l to 68mg/l these values are well below the WHO guidelines for drinking water, NAMWATER has no set TDS standard. Figure 9 illustrates the TDS variations at different sampling points along the Canal from February to April 2008.

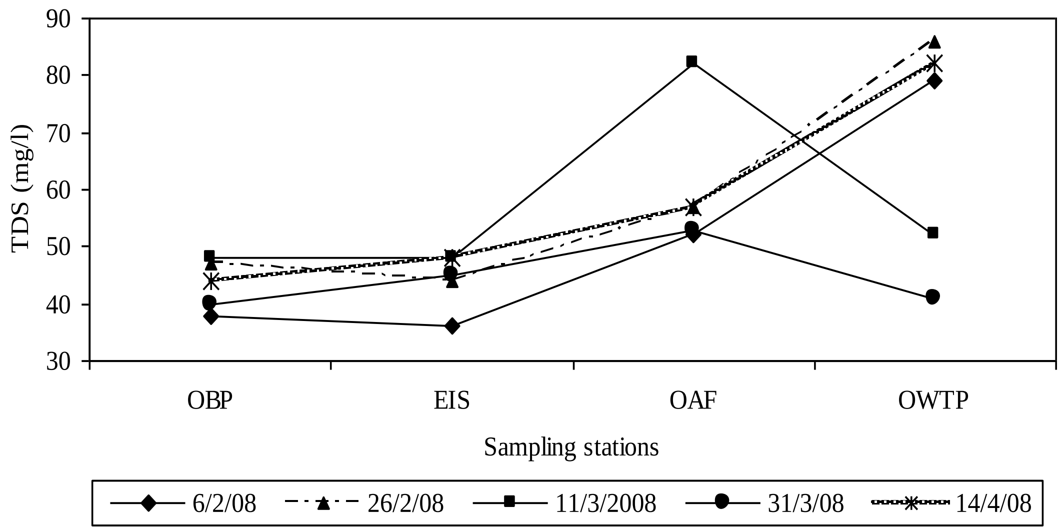

Figure 9: TDS variations at sampling sites for February to April 2008.

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

An increasing trend in TDS levels from upstream to down stream the Canal was observed, this could be attributed to the increase in salts concentration arising from the surrounding geology through overland flow. The soil in the area consists of clayey sodic soils in the lower parts of the land scape and sodic sands on surrounding relatively higher grounds this high sodium content in the soil is a result of repeated flooding in the basin (Mendelsohn *et al.*, 2002). The lower parts of the landscape (water channels) have the highest salt concentration and the Canal cuts across these channels and when flooded the water from these channels gets into the Canal which could lead to the increase in TDS concentrations. The other possible source of increasing the TDS concentration is the pollution from the surrounding villages, grazing lands and towns getting into the Canal through overland flow. On the

11/3/2008, the OAF station recorded the highest TDS concentrations; this could be attributed to the increase in salt content due to overland flow as heavy rains were experienced on the day.

TDS concentrations of the Canal water was lower compared to similar studies carried out on streams in Malawi by Sajidu *et al* (2007) were TDS concentrations ranged from 247mg/l to 586mg/l. as well as other studies by Olajire and Imeokparia (2000) on the Osun River in Nigeria and by Germs *et al* (2004) on the Chinus River in South Africa which measured TDS concentrations ranging from 138-732mg/l and 63.8-331mg/l respectively. These TDS concentrations are higher than in the Canal water however they are all within the WHO guidelines for drinking water of 1000mg/l above which water become unpalatable (WHO, 2006).

- *Suitability of Canal water TDS content for agricultural use*

Irrigation water contains a mixture of naturally occurring salts; soils irrigated with this water will contain a similar mix but usually at a higher concentration than in the applied water (Ayers and Westcot, 1994). Each irrigation campaign adds salts to the soil, these salts will reduce crop yield by accumulating at root depth. According to Fipps (2003) excessive accumulation of soluble salts in the soil causes water stress for crops by plugging clay and humus into soil pores reducing the ability for the crops to extract water from the soil. The value of TDS 160mg/l is considered to have very low hazard and does not cause soil build-up of salt while TDS of above 1920mg/l is considered to have a high hazard and is generally unacceptable for irrigation, except for very salt-tolerant plants where there is excellent drainage, frequent leaching, and intensive management (Hopkins, *et al.*, 2007). According to Ayers and Westcot (1994) water with elevated salinity or water containing toxic elements may be hazardous to animal health and may even render the milk or meat unfit for consumption and occasionally water with high salt content (above 895.5mS/m) may cause physiological upset or even death in livestock, with the main reported effect being depression of appetite caused by a water imbalance rather than related to any specific ion.

The water in the Canal was suitable for agricultural use as the average TDS values at all the four sampling points along the Canal ranged between 43mg/l-68mg/l which was well below 160mg/l mark, which is considered to have low hazard in causing salt build up in the soil. The TDS levels in the water are also well below levels that will cause yield reductions in crops farmed at the Etunda Irrigation Scheme refer to Appendix A. The water quality in terms of TDS is also within the NAMWATER standards for stock watering shown in Tale 3B in Appendix B**.**

- *Suitability of Canal water TDS content for fisheries*

Sodium is not considered a critical water parameter in determining suitability for fisheries suggested by Pe´rez, (2001) and Chapman (1996), however according to Kirk (1984) noted that increased levels of dissolved solids results in the reduction of DO in the water which causes the death to aquatic species e.g fish.

- *Suitability of Canal water TDS content for potable use*

According to (Ribaudo *et al.*, 2000) increased levels of dissolved solids in public drinking water can increase water treatment costs, force the development of alternative water supplies, and reduce the life spans of water-using household appliances. TDS is comprised of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) and small amounts of organic matter that are dissolved in water. TDS in drinking-water originate from natural sources, sewage, urban runoff and industrial wastewater. According to WHO (2006) the palatability of the water with a TDS level of less than 600mg/l is generally considered to be good; drinking-water however become significantly and increasingly unpalatable at TDS levels greater than about 1000mg/l. Water with elevated (above 600 mg/l) TDS tastes salty and does not slake thirst, consumption of water with elevated TDS may not produce adverse health effects in the short-term, but there is a slight possibility of salt overload in sensitive individuals in the long term (Hohls *et al.,* 2002).The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances.

The water in the Canal was suitable for human consumption as it was well below the set NAMWATER standard. The TDS levels in the water at all station falls below 600mg/l which constitute good water quality. However TDS have long term impacts such as need to replace pipe lines due to corrosion and shortening of Compared to other similar studies in the region earlier mentioned recorded higher levels of TDS compared to the Canal water but did not find TDS related water quality problems

5.1.6. Suitability of Canal water Sodium content for various uses

The summary of the sodium results at the four sampling stations is presented in Table 3. The average sodium concentration at the four sampling station ranged from 5mg/l to 14mg/l. These concentrations were all within the NAMWATER standard and WHO guidelines for drinking water. Figure 10 illustrates sodium variations at different sampling points along the Canal from February to April 2008.

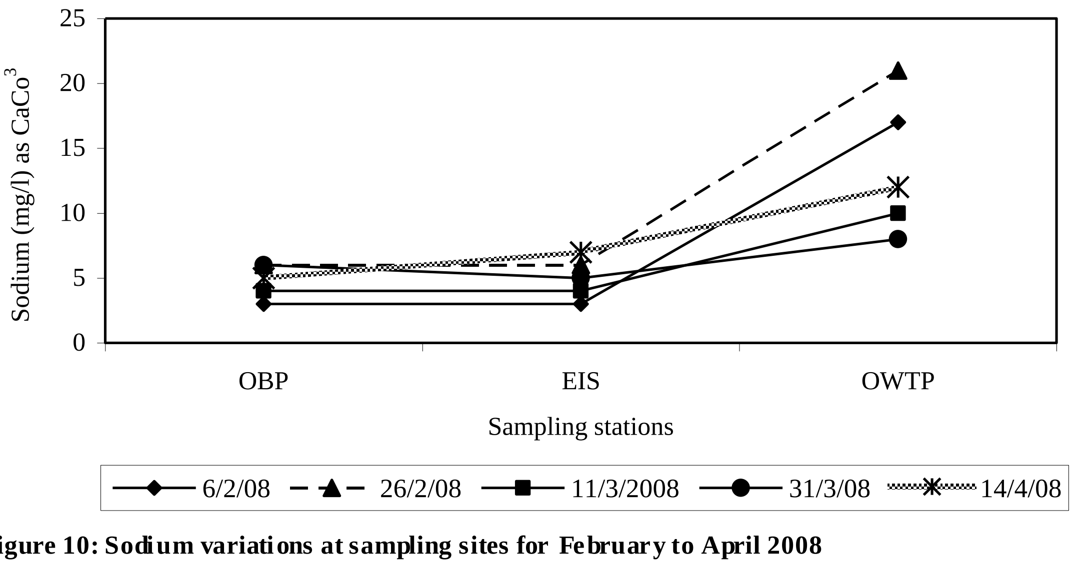

Figure 10: Sodium variations at sampling sites for February to April 2008

**OBP Omahenene Border Post*

EIS Etunda Irrigation Scheme

OAF Omahenene Aquaculture Farms

OWTP Oshakati Water Treatment Plant

Sodium concentration showed an increasing trend from upstream to down stream with significant increases observed at OBP and OWTP. This can be attributed to the increase in sodium content from overland flow. The soil in the area is classified as sodic soils (soil high in sodium content) this is a result of continuous flooding in the basin (Mendelsohn *et al.*, 2002). The lower lying landscape areas (water channels) are high in sodium content the Canal cuts across these channels, flood water from these channels find their way into the Canal which could be the reason in increasing sodium content in the Canal. The sodium content could also be increasing as a result of anthropogenic activities through runoff from the surrounding grazing areas, settlements and towns.

- *Suitability of Canal water sodium content for agricultural use*

The sodium content of irrigation water is important because of its effect on both the soil and plants. Elevated sodium concentrations in irrigation water adversely effect soil structure causing the soil surface to become hard and difficult to cultivate, prevents seedling emergence and reduces infiltration (Lantzke, 2004). In addition to salinity, some crops are injured by certain elements notably sodium, with drip and furrow irrigation systems Sodium injury do not occur but under sprinkler irrigation, injury may occur to wetted leaves of susceptible plants such as pepper, potatoes and tomato if the salinity exceeds TDS of 960mg/l (Grattan, 2002). Sodium in irrigation water is absorbed through leaves wet by the sprinklers resulting in leave burns (Ayers and Westcot, 1994)

The water in the Canal was considered good for agricultural use, as the sodicity of the water was suitable for all the crops farmed at Etunda Irrigation Scheme. The sodium concentrations in the Canal water are also well below levels that could cause damage to irrigated plants especially when irrigated with sprinkler system which is used at the Etunda Irrigation Scheme as suggested by (Grattan, 2002). The sodium water content is also well below the levels attributed to the death of 91 out of 80 cows in Mexico were the sodium concentrations were found to be around 21160mg/l (Ayers and Westcot, 1994).

- *Suitability of Canal water sodium content for fisheries*

Sodium is not considered a critical water parameter in determining suitability for fisheries suggested by Pe´rez, (2001) and Chapman (1996).

- *Suitability of Canal water sodium content for potable use*

All natural waters contain some sodium and sodium salts are highly soluble in water and it one of the abundant elements on earth, Sodium concentration in natural surface waters may vary considerably depending on local geological conditions and waste water discharges. Values can range from 1 mg/l or less to 10^5mg/l or more in natural brines (Chapman, 1996) and typical potable water has a concentration of about 20 mg/l (Michael *et al.*, 2002).There are no health based guidelines on sodium as there is no sufficient evidence to justify a guideline value for sodium in water based on health risk considerations (WHO, 2006). The American Heart Association recommended a drinking water concentration of 20 mg/l of sodium (AWWA, 1990). Concentrations in excess of 200mg/l may give rise to unacceptable taste (WHO, 2006). Too much sodium intake in food and water has been identified as a contributor to high blood Pressure (Michael et al., 2002). The American Heart Association and National

Academy of Sciences recommend Sodium levels between 500 and 2,400mg/day. However, sodium less than 1,800mg is believed to be healthier.

The water in the Canal was considered suitable for potable use as it is well within the NAMWATER standard for drinking water and the recommended sodium concentration in the drinking water by the AWWA (1990). Similar studies in the region referred to earlier recorded higher sodium concentrations but did not observe sodium related problems concerning water use for domestic purposes.

5.1.7. Suitability of Canal water Calcium content for various uses

The summary of calcium concentrations at the four sampling stations is presented in Table 3**.** The average calcium concentration at four sampling stations ranged between 10mg/l and 13mg/l, these concentrations were all within the NAMWATER standard of 150mg/l. Figure 11 illustrates calcium variations at different sampling points along the Canal from February to April 2008.

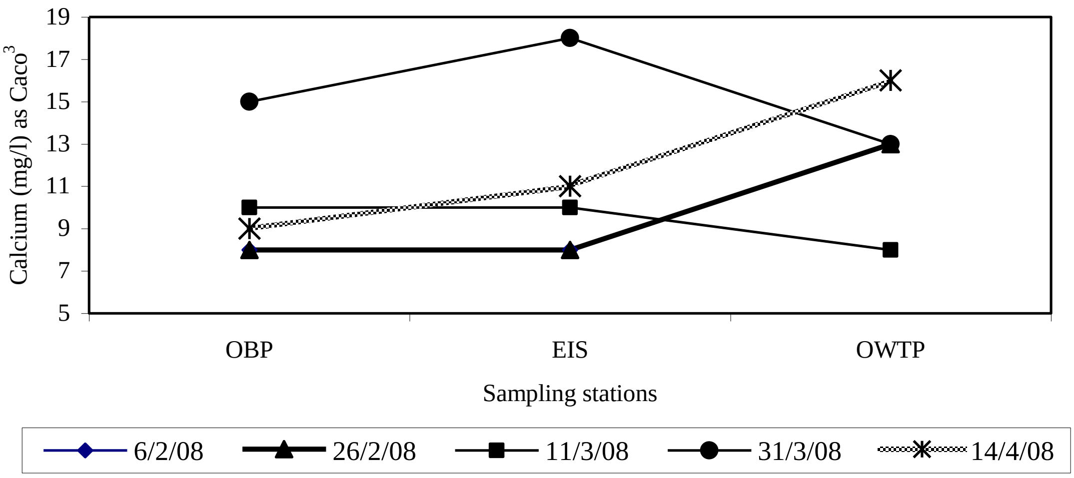

Figure 11: Calcium variations at sampling site for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

There is an increasing trend in calcium concentration from upstream to downstream with significant increases at OBP and OWTP. This increase in calcium content can be attributed to overland flow rich in calcium content. The geology in the area consist of a mosaic of soil types, usually comprising of one dominant soil that generally covers more than half an area, for simplicity it is often best to group areas according to the dominant soils (Mendelsohn *et al.*, 2000). The runoff could have originated from soils rich in calcium content or the increase in calcium content could be due to anthropogenic activities from the surrounding grazing areas, villages and towns through runoff as suggested by Chapman (1996) who noted that calcium may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes.

The calcium concentration in the Canal were lower compared to similar studies carried out by Germs *et al* (2004) on the Chinus River in South Africa and Olajire and Imeokparia (2000) on the Osun River in Nigeria which measured concentration ranging from 26-56mg/l and 14-37mg/l respectively. Although these concentrations are higher than those in the Canal they are all within the WHO guidelines for drinking water.

- *Suitability of Canal water calcium content for agriculture*

Relatively high sodium or low calcium content of soil or water reduces the rate at which irrigation water enters soil to such an extent that sufficient water cannot be infiltrated to supply the crop adequately (Ayers and Westcot, 1994). According to Grattan (2002) the surface soil aggregates then disperse to much smaller particles which clog soil pores. Calcium concentration in natural waters are typically less than 15mg/l , for waters associated with carbonate-rich rocks concentrations may reach 30-100mg/l (Chapman, 1996). The ratio of Ca/Mg in the soil-water is used to predict a potential calcium deficiency and ratios of less than 1 is associated with calcium deficiencies (Ayers and Westcot, 1994). Plants take up calcium in the ionic form (Ca^2+), when calcium deficiency is prevailing calcium uptake is not as efficient as that for other plant nutrients (Incitec Pivot, 2003). Adverse weather conditions, such as drought, low temperatures, high humidity, poor soil aeration and water logging are the known causes of calcium deficiency Table 5 present the calculated calcium deficiency at the three sampling points from February to April 2008.

Table 5: Calcium deficiency ratio at the three sampling stations between February and April 2008.

Calcium Deficiency			
Date	**OBP**	**EIS**	**OWTP**
6/2/2008	2	2	1.6
26/2/2008	2	1.6	1.3
11/3/2008	2.5	2.5	2.0
31/3/2008	1.9	2.3	0.6
14/4/2008	1.5	1.6	0.9
Average	**2.0**	**2.0**	**1.3**

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OWTP Oshakati Water Treatment Plant

The Canal water was suitable for irrigation as it was within the natural water range of below 15mg/l, thus does not pose any infiltration problem associated with elevated calcium levels. The average calcium/magnesium ratio values were above 1 meaning the water does not pose the danger of calcium deficiency in crops associated with calcium/magnesium ration of below 1.

- *Suitability of Canal water calcium content for fisheries*

Calcium is not considered a critical water parameter in determining suitability for fisheries suggested by Pe´rez, (2001) and Chapman (1996). There is no set standard calcium concentration for fisheries.

- *Suitability of Canal water calcium content for potable use*

Calcium salts and calcium ions are among the most commonly occurring in nature (Chapman, 1996). They may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes. Calcium is usually one of the most important contributors to hardness. Calcium concentration in natural waters are typically less than 15mg/l , for waters associated with carbonate-rich rocks concentrations may reach 30-100mg/l (Chapman, 1996). Even though the human body requires approximately 0.7 to 2.0grams of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones (AWWA, 1990).

The Canal water was suitable for human consumption as the calcium concentration at all sampling points were within the NAMWATER standards and the WHO guidelines for drinking water. Compared to similar studies carried out by Germs *et al* (2004) on the Chinus River in South Africa and Olajire and Imeokparia (2000) on the Osun River in Nigeria which measured concentration ranging from 26-56mg/l and 14-37mg/l respectively which are higher then those in the Canal did not report any calcium related problems from use of the water as a potable source.

5.1.8. Suitability of Canal water Magnesium content for various uses

The summary of magnesium concentrations at the four sampling stations is presented in Table 3. The average magnesium concentration at all sampling points ranged from 5-12mg/l. Magnesium concentrations at all sampling points were within the NAMWATER standard of 290mg/l as $CaCo_3$, and the WHO guidelines for drinking water of 200mg/l. Figure 12 illustrate magnesium variation at different sampling stations along the canal from the 6 March to 14 April 2008.

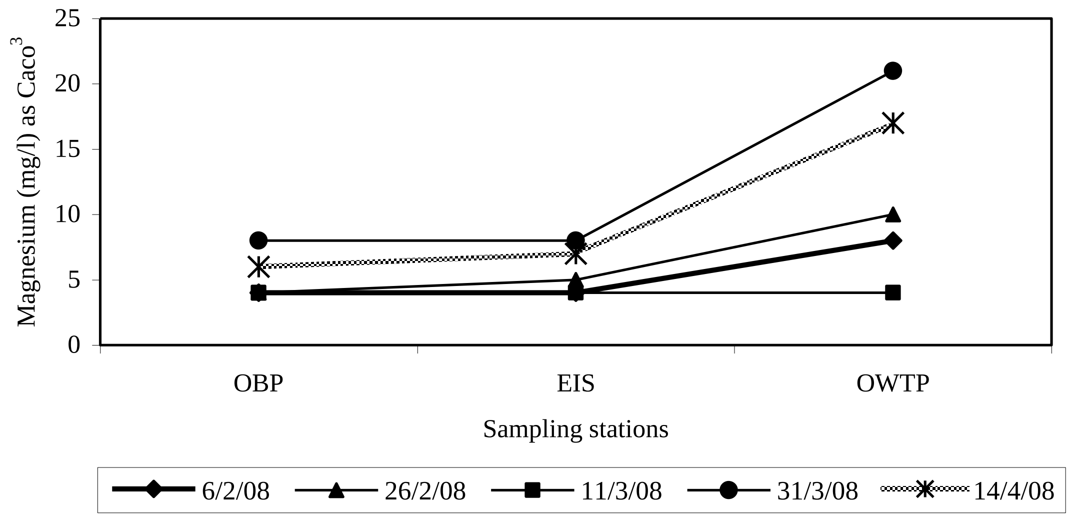

Figure 12: Magnesium variations at sampling sites for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

There is an increasing trend from upstream to down stream with significant increase occurring at EIS and OWTP this could be attributed to magnesium rich overland flow getting into the Canal. The geology in the area consist of a mosaic of soil types, usually comprising of one dominant soil that generally covers more than half an area, for simplicity it is often best to group areas according to the dominant soils (Mendelsohn *et al.*, 2000). The runoff could have originated from soils rich in magnesium content or the increase is a result of human and animal waste getting into the Canal from the surround settlements, towns and grazing areas.

The Magnesium concentration in the Canal was lower than those recorded by a similar study by Germs et al (2004) on the Chinus river in South Africa which had concentration ranging from 24-170mg/l. this concentration are higher than the Canal concentrations but they are all within the WHO guidelines for drinking water.

- *Suitability of Canal water magnesium content for agriculture*

Soils containing high levels of exchangeable magnesium are often thought to be troubled with soil infiltration problems (Ayers and Westcot, 1994). Magnesium and Calcium are usually the most important contributors to water hardness (Chapman, 1996). Magnesium is known to cause scouring and diarrhoea in live stocks (Ayers and Westcot, 1994). Australian standards recommend that magnesium be taken into account, particularly if the EC_w exceeds 4000mg/l for cattle and 6000mg/l for sheep watering.

The Canal water quality was suitable for irrigation use and for stock watering as the magnesium concentration at all sampling stations were within NAMWATER standards for stock watering. Compared to a similar study carried out by Germs *et al.* (2004) on the Chinus River in South Africa did not report of magnesium related problem in agriculture due to the use of the water as a source of irrigation water.

- *Suitability of Canal water magnesium content for fisheries*

Magnesium is not considered a critical water parameter in determining suitability for fisheries suggested by Pe´rez, (2001) and Chapman (1996). There is no set standard magnesium concentration for fisheries.

- *Suitability of Canal water magnesium content for potable use*

Magnesium is common in natural waters and along with calcium are the contributors to water hardness (Chapman, 1996). Magnesium arises principally from the weathering of rocks containing Ferro magnesium minerals and from some carbonates rocks and is a contributor to water hardness. Natural concentration of magnesium in fresh waters may range from 1mg/l to less than 100mg/l, depending on the rock types in the Catchment (Chapman, 1996).

The water in the Canal was suitable for potable use as the concentration levels were within the NAMWATER standard for drinking water and similar studies by Germs *et al* (2004) on the Chinus River in South Africa which had higher concentration of magnesium of 24-170mg/l compared 5-12mg/l in the Canal did not report magnesium related problems as a result of using the water as a potable source.

5.1.9. Sodium Absorption Ratio (SAR) suitability for agricultural use

The average calculated SAR values ranged from 1.7 to 4.2. The SAR values showed an increasing trend from OBP to OWTP. SAR is the measure of the sodicity of irrigation water, which is the extent of dissolved sodium that can possibly determine the soil physical condition and pose infiltration and permeability problems, ultimately affecting the plant growth (Ayers and Westcot, 1994). As SAR is calculated from the ratio of sodium and calcium plus magnesium concentration in the water the reasons for the SAR value variation is due to the increase of these elements resulting from overland flow getting into the Canal which have elevated TDS concentrations as a result of the geological influence or pollution from anthropogenic sources from the surrounding villages, towns and grazing areas. According to the SAR classification adopted from Fipps (2003) presented Table 3A in Appendix A. all sampling stations falls into the low SAR category, it is recommended that the use of this water on sodium sensitive crops such as avocados must be cautioned. Figure 13 illustrates the SAR values variations at different sampling points along the Canal from February to April 2008.

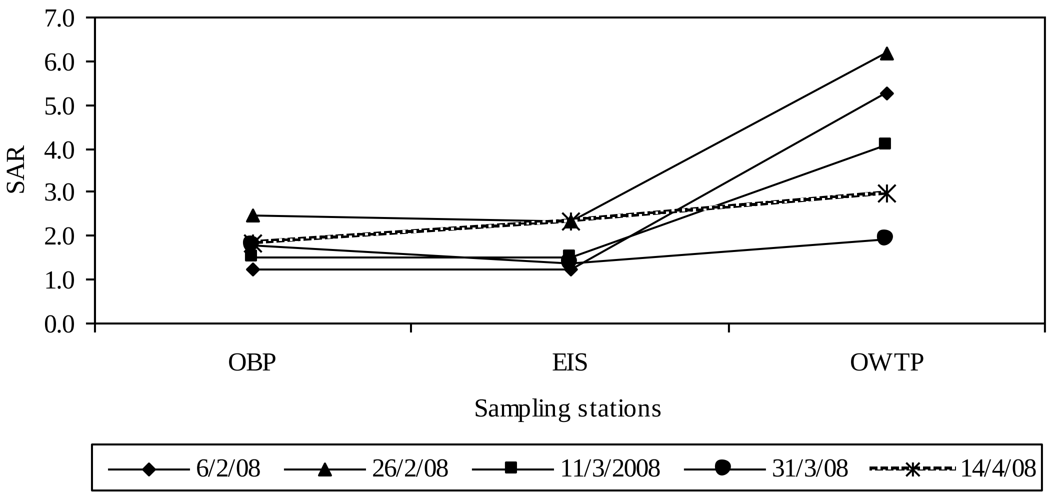

Figure 13: SAR variations at sampling sites for February to April

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

The water in the Canal had low SAR which made it suitable to irrigate all crops types farmed at Etunda Irrigation Scheme, but would however be unsuitable for irrigating sodium sensitive crops such as avocadoes. The low SAR in the water also means there was no danger in breakdown of physical soil structure associated with the continued use of water with high SAR (18-19) as suggested by Fipps (2003).

5.1.10. Suitability of Canal water Total hardness content for various uses

The summary of total hardness concentration at the four sampling stations is presented in Table 3. The average total hardness values ranged from 15mg/l $CaCo_3$ at OBP to 24mg/l at OWTP. The values at all three sampling stations are within the NAMWATER standards. However there is an increasing trend from OBP to OWTP and the increasing trend is directly linked to the increase in amount of calcium and magnesium concentrations along the Canal. This could be attributed to the geological impacts on the runoff getting into the Canal and the anthropogenic activities along the Canal. The high levels of hardness on the 31/3/2008 could be attributed to calcium rich runoff on the day of sampling as a result of either geological influence or anthropogenic influence on the runoff. Figure 14 illustrates total hardness variation at the three sampling stations from February to April 2008.

The total hardness concentration in the Canal were lower than those from a similar study by Olajire and Imeokparia (2000) on the Osun River in Nigeria which measured concentrations ranging from 84.6-1170mg/l. the concentration are within the WHO guidelines for drinking water although the upper limit is beyond the threshold of 500mg/l.

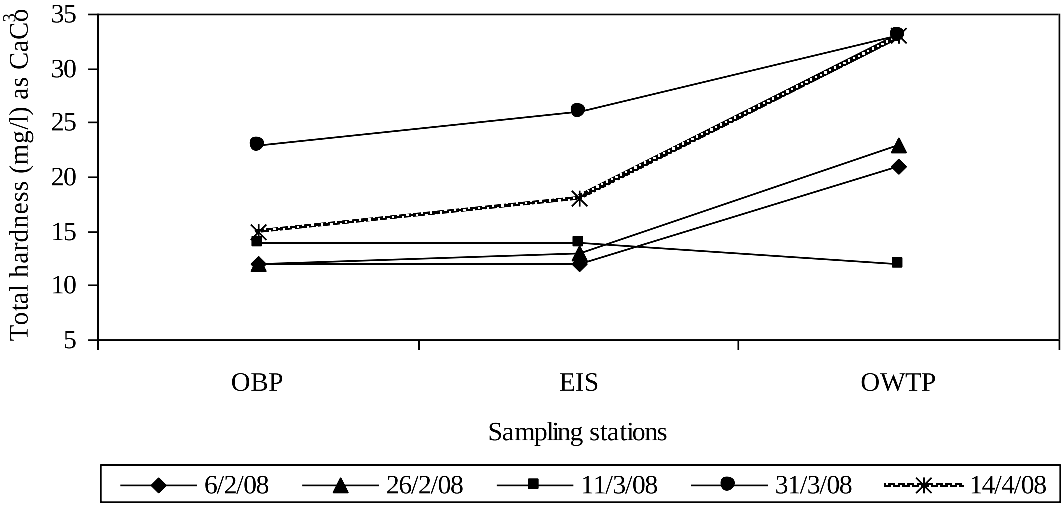

Figure 14: Total hardness variations at sampling sites for February to April 2008

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

- *Suitability of Canal water total hardness content for agricultural use*

Harder water has the effect of reducing the toxicity of some metals such as copper, lead and zinc (Chapman, 1996). Soft water may have corrosive effect on metal plumbing, while hard water may result in scale deposits in the pipes (WHO, 2006).

The water in the Canal was considered suitable for agricultural use as its soft in nature. This can lead to corrosion of irrigation pipes, from the interview with the farm manager and the water treatment plant workers corrosion is not one of the major water quality related problems experienced.

- *Suitability of Canal water total hardness content for fisheries*

Total hardness is not considered a critical water parameter in determining suitability for fisheries suggested by by Pe´rez, (2001) and Chapman (1996). There is no set standard for total hardness concentration for fisheries; however Alabaster (1982) found that if the water is hard, sufficient free carbon dioxide may be liberated to be toxic to fish.

The water in the Canal was not classified as hard according WHO (2006) hard water has total hardness of above 100mg/l $CaCo_3$ and thus will not result in free carbon dioxide being liberated, this make the water in the Canal safe for fisheries use.

- *Suitability of Canal water total hardness content for potable use*

Hardness is generally defined as the sum of the polyvalent cations present in the water and expressed as an equivalent quantity of calcium carbonate ($CaCo_3$). The most common such cations are calcium and magnesium (AWWA, 1990). Calcium and magnesium are the primary cations in fresh water because of their predominance in sedimentary rocks. Hardness in the water is caused by dissolved calcium and, to a lesser extent, magnesium. Depending on pH and alkalinity, hardness above about 200mg/l can result in scale deposition, particularly on heating (WHO, 2006). Soft waters with a hardness of less than about 100mg/l have a low buffering capacity and may be more corrosive to water pipes (WHO, 2006). Hard water typically containing elevated concentrations of Ca, Mg (and other) cation, makes it difficult to obtain a lather with soap (Lantzke, 2004). Generally softening is not necessary unless the total hardness exceeds 200mg/l (AWWA, 1990). Public acceptability of the degree of hardness of water may vary considerably from one community to another, depending on local conditions; consumers may tolerate water hardness in excess of 500mg/l (WHO, 2006).

The Canal water was suitable for potable use as its total hardness concentration were within the set NAMWATER standard of 300mg/l and the threshold levels were consumer tolerate hardness. The hardness levels were not above 200mg/l which causes scale deposition in pipes and distribution system; however the Canal can be classified as soft water (< 100mg/l) which is associated with corrosion of pipes. The soft nature of the water makes it suitable for other house hold uses such as washing as it is easy to obtain lather with soap.

5.1.11. Suitability of Canal water Nitrate content for various uses

The nitrate concentration at all sampling point on all the sampling campaigns was found to be less than 0.1 mg/l at all the sampling stations along the Canal as presented in Table 4. These concentrations are well with in the NAMWATER standard as well as the WHO guidelines for drinking water. The nitrate concentration in the Canal were low compared to similar studies by Germs *et al.* (2004) on the Chunies River in South Africa which recorded nitrate concentrations ranging from 0.07-9.69mg/l these concentration are below the WHO guidelines for safe limit of drinking water of 10mg/l. a similar study on the Umtata River in south africa by Fatoki *et al.* (2001) measured nitrate concentrations that are beyond the WHO safe limit making the water unsuitable for direct potable use as it exposes infants and pregnant woman to the risk of methaemoglobinemia. Further similar studies by Chimwanza *et al* (2005) on Likangala River in Malawi, and by Sajidu *et al* (2007) on streams in Malawi which measured nitrate concentrations ranging from 0.18- 0.39mg/l and 0.81-20.18mg/l. the nitrate concentration in the Canal is comparable to a study Akoto and Adiyiah (2007) on Brong Ahafo regions in Ghana which measured concentrations ranging from 0.09-0.99mg/l.

The water in the Canal was considered suitable for potable use as it was within the NAMWATER standards and the WHO guidelines for drinking water. Nitrate in the Canal was also suitable for fisheries based on the fact that there is a practice at the aquaculture farms of adding cow dug to the fish ponds to encourage algal growth.

5.1.12. Suitability of Canal water in terms of Escherichia coli (E.coli) counts for various uses

The summary of E.coli results at the four sampling stations is presented in Table 4. Average E coli counts for all sampling points ranged from 7-42MPN per 100ml of water (lowest at OBP and highest at OWTP). The variation in total E.coli counts showed an increasing trend from upstream the Canal to down stream the Canal. This can be attributed to cumulative faecal contamination from the surrounding urban, villages and surrounding grazing areas through overland flow or direct contamination. Some stretches of the Canal supports shrubs that human use for convenience and when it rains it gets washed into the Canal. Other sources are pollution from animal wastes as some watering points and kraals are situated near the Canal and when it rains the wastes gets washed into the Canal. Figure 15 illustrates E.coli variations at different sampling stations from February to April 2008.

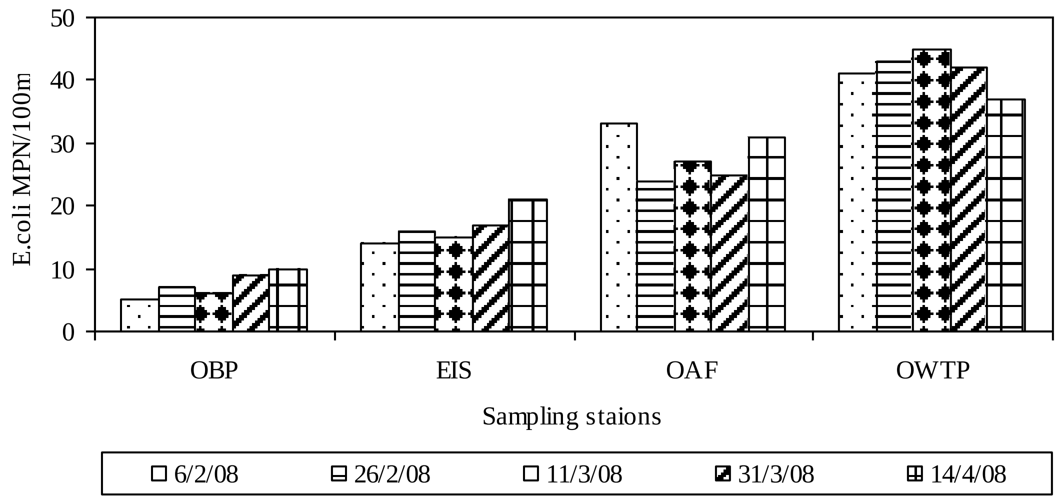

Figure 15: E. coli variation at Sampling Points for February to April

**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

The amount of E.coli in the Calueque-Oshakati Canal was comparable to a similar study by Germs *et al* (2004) on the Chunies River in South Africa which found E.coli ranging from 6-40 E.coli/100 ml. A similar study on Umtata River in South Africa by Fatoki *et al.* (2001) which lack proper sanitation observed significant increase in E.coli further down stream compared to up stream and this was attributed to runoff from urban and settlements along the river. In both studies it was concluded that there was a definite possibility of contamination from eating raw vegetables and other crops irrigated with water from this sources.

- *suitability of Canal water E.coli counts for agricultural use*

E.coli is not considered a critical water parameter in determining suitability for agricultural use suggested by Fipps, (2003), Hopkins, *et al* (2007) and Ayers and Westcot, (1994). However According to WHO guidelines for irrigation water recommend that there should be less than 1000 E.coli/100 ml in water intended for irrigation of crops likely to be eaten uncooked (Tyrrel, 1999). The water in the Canal was considered suitable for irrigation even for the crops that were to be eaten uncooked as it is below these levels. As similar study by Germs *et al* (2004) on the Chunies River in South Africa which found E.coli ranging from 6-40 E.coli/100 ml concluded that there was potential contamination from eating uncooked crops irrigated with that water.

- *Suitability of Canal water E.coli counts for fisheries*

E.coli is not considered a critical water parameter in determining suitability for fisheries suggested by Pe´rez, (2001) and Chapman (1996).

- *Suitability of Canal water E.coli counts for potable use*

The presence of faecal coliform bacteria indicates that the water has been contaminated with the faecal material of man or other animals (SEED, 2003). At the time this occurred, the source water may have been contaminated by pathogens or disease producing bacteria or viruses which can also exist in faecal material. The presence of faecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. Faecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or non-point sources of human and animal waste (SEED, 2003).

NAMWATER standards and WHO guidelines for drinking water require zero presence of E.coli per 100 ml of drinking water. On this basis the water in the Canal was not fit for human consumption without treatment.

5.2. Pollution load

The pollution loads of the different parameters at different sampling points are presented in Table 6 and Figure 15 show the total pollution loads along the Canal.

Table 6: pollution loads of the measured parameters at the four sampling stations between February and April 2008 presented in kilograms per day (kg/day).

Stations	Turbidity	Sodium	Calcium	Magnesium	Total hardness	TDS	TPL
OBP	823	35	69	35	104	297	1362
EIS	995	35	76	35	111	304	1555
OAF	1583	ns	ns	ns	ns	415	1998
OWTP	1638	97	83	76	166	470	2530

*******Discharge was assumed to be 0.8 m^3/s at all sampling points.*
** ns Not sampled*
**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant
TPL Total Pollution Load

All the measured parameters are showing an increased pollution load from upstream to down stream (OBP-OWTP) this could be attributed to the cumulative effect of overland flow from the surrounding villages, urban centres and grazing lands getting into the Canal. The Canal passes through communal lands, urban centres that lack proper sanitation facilities and proper refuse dumps runoff from these areas could contribute to water pollution in the Canal. Figure 16 presents the total pollution loads of different sampling stations from February to April 2008.

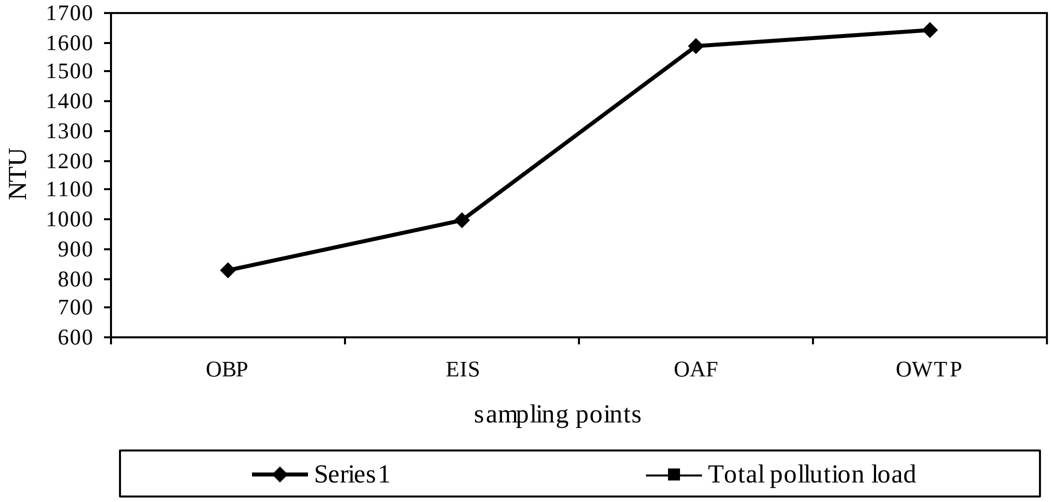

Figure 16: Trend of total pollution load along the Canal for February to April 2008
**OBP Omahenene Border Post*
EIS Etunda Irrigation Scheme
OAF Omahenene Aquaculture Farms
OWTP Oshakati Water Treatment Plant

According to UN/ECE (2000) Pollution load estimates are used to assess the total input of pollutants to a river and the pollution load of that river to receiving waters (lakes, reservoirs, seas). Pollutant load estimation is a fundamental element in the development of many Catchment management plans. Reliable estimates of the quantity of pollutants delivered from various sources within a Catchment are needed to develop a Catchment plan that will address the identified water quality problems or issues (EPA, 2003) the water in the Canal is transported from a different basin through areas with different land uses and geology that can impact on water quality, it is imperative to estimate the pollution loads from different sources in order to device management options that will decrease pollution loads from the different sources. In this study it was found that the possible sources to the Canal water is runoff from the surrounding villages and urban centres that lacks proper sanitary facilities as well as from grazing areas and kraals and other developments that are located to close to the Canal (in the buffer zone) and direct dumping into the Canal.

5.3. Implications of water pollution on the water purification process.

Two water quality parameters were of interest in determining the impacts of pollution on water treatment, water pH and turbidity. Water pH was chosen on the basis that the speed and degree of coagulation and flocculation, and the removal of turbidity are extremely pH sensitive (Heinonen and Lopez, 2007). While turbidity was chosen because it increases the amount of chlorine required for disinfection. The Olushandja water treatment plant is the furthest upstream the Canal and consists of two processes for purifying water; a batch plant and slow sand filters with the capacities of 1600m^3/day and 740m^3/day respectively. The Ombalantu (Ombalantu) water treatment has a capacity of producing 66m^3/h of water. The water purification process starts with coagulation and flocculation and disinfection in the flash mixer followed by settling, filtration and finally post production disinfection, the package plant uses only flocculants without lime. The Ogongo treatment plant purification process starts with flocculation and disinfection in the flash mixers, followed by settling then filtration and then finally post production disinfection the plant has a capacity of producing 1500 m^3/h of water. The Oshakati Water Treatment Plant is the furthest down stream the Canal and is the second largest plant in the country with the capacity of producing 2000 m^3/h of water. The purification process starts with coagulation and flocculation, then settling followed by filtration and then post production disinfection. Table 7 presents the minimum and maximum monthly averages of pH, turbidity and dosages of coagulants, pH adjusters and the disinfectant used to purify 1 m^3 of water.

Table 7: Minimum and maximum yearly averages of turbidity, pH, coagulant dose (kg/m^3), chlorine dose (kg/m^3) and chemical cost (N$/ m^3) at the four water treatments plants for the year 2006/2007.

	Olushandja		Ombalantu		Ogongo		Oshakati	
	Min	Max	Min	Max	Min	Max	Min	Max
Turbidity	16	138	22	191	31	188	27	362
pH	9	12	7	9	8	9	7	9
Coagulant (kg/m^3)	100	546	52	253	21	95	25	266
Chlorine (kg/m^3)	356	694	118	304	247	444	3254	28926
Chemicals Cost (N$/$m^3$)	1	5	1	11	3	6	2	58

(Source: NAMWATER)

5.3.1. Turbidity

The average NTU values at all the four treatment plants were found to range from 16-362 as shown in Table 7. The average values at the all the treatment plant are above the NAMWATER standard and WHO recommended guidelines for drinking water which makes the water unsuitable for human consumption without treatment. Figure 17 present the monthly average turbidity at all the four sampling plants for the year 2006/2007

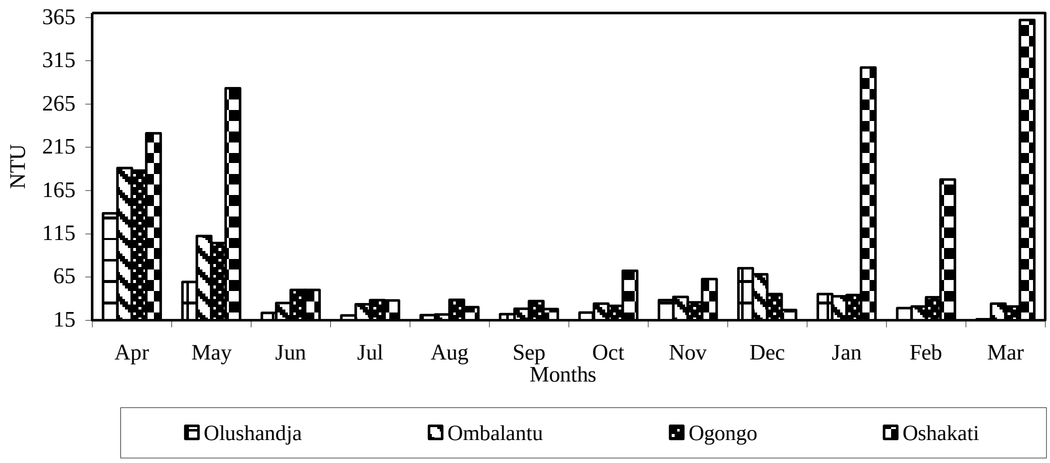

Figure 17: Monthly average NTU values at the four treatment plants for 2006/2007

Some surface water might be less polluted and only filtration and disinfection are enough to obtain purified water (NAMWATER, 2008). The average values at all the treatment plants are above the required range (between 1 and 5 NTU) for effective disinfection (WHO, 2006) and thus have to be treated before disinfection can be effective.

On average the high turbidity coincides with the rain season as shown in Figure 17, which occurs from October to May in Namibia. According to the AWWA, (1990) periods of heavy precipitation, results in high rates of runoff or flood conditions, which cause resuspension of sediments and increases turbidity. According to Pernitsky (2003) coagulant doses are generally higher when raw water turbidity increases, although the relationship is not linear. Turbidity puts an excess load on water treatment plants by interfering with the filtration process and generating extra sludge (O'Neill *et al.,* 1994). Due to the elevated turbidity during rainy season treatment plants upstream carry out backwash of filters once a week and as much as three times a week at treatment plants down stream according to plant supervisors. Turbidity interferes with the efficiency of disinfection and often signals the presence of other health hazards (John, 1977). The amount of disinfectants increases with increase in turbidity. The average low turbidity occurred in the winter months which stats in June to September this can be attributed to the absence of overland flow (runoff) getting into the Canal. The rainfall season in the Catchment area in Angola is similar to that in Namibia the flow in the Kunene River is likely to be predominantly from base flow which is usually low in turbidity. On average the Oshakati treatment plant recorded the highest average turbidity and this could be attributed to the effect of cumulative runoff into the Canal as the Oshakati treatment is the furthest down stream. While lowest average turbidity was recorded at the Olushandja treatment plant which is the furthest upstream the Canal this due to limited cumulative impact of overland flow as compared to the other treatment plants further down stream.

5.3.2. pH

The minimum and maximum monthly averages of pH values at all the four treatment plants are presented in Table 7. The average pH values ranged from 7-12 and were all within the NAMWATER standard and WHO guidelines for drinking water except at the Olushandja treatment plant. This could be attributed to the low water salinity (TDS <128mg/l) which according to Ayers and Westcot (1994) can sometimes lead to pH outside the normal range (6-9) due to its limited buffering capacity. Figure 18 present the average monthly pH values at the four treatment plants compared with the NAMWATER standard for drinking water and WHO guidelines for effective disinfection with chlorine.

The average monthly pH at the four treatment plants were above the pH of 6.5 which is associated with significant corrosion. However the average pH values at all the treatment plants were above the pH of 8.5 which increases the frequency of incrustation and scaling problems (Robert, 2007). According to AWWA (1990) the adjustment of pH is the most common method of reducing corrosion in the distribution system. The average pH values at all the treatment plants are above the WHO recommended optimum pH range for effective disinfection with chlorine which should be less than 8 except for the Ombalantu treatment plant. According to AWWA

(1990) the half-life of aqueous chlorine dioxide solution decreases substantially with increasing concentration and with pH values above 9.

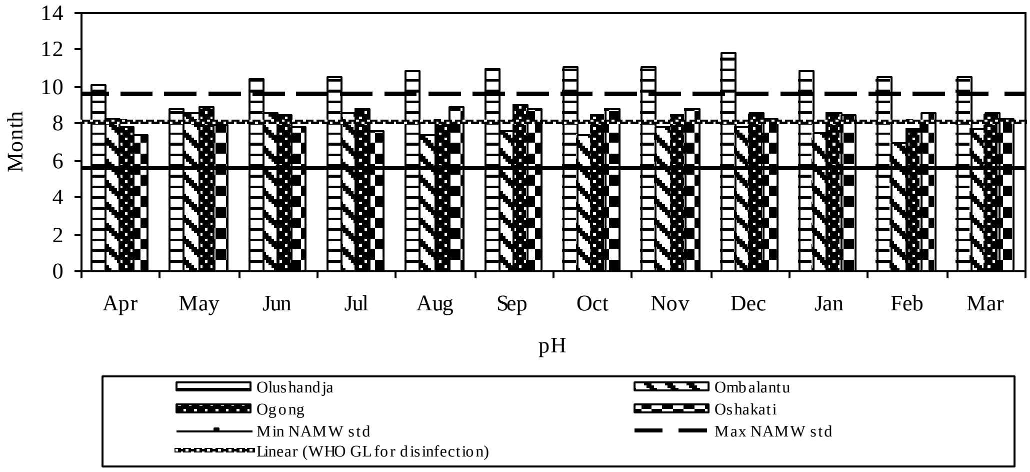

Figure 18: Monthly pH values at the four treatment plants for 2006/2007

5.3.3. Coagulants

The minimum and maximum monthly average amounts of coagulant used to produce a m^3 of water at the four treatment plants were found to range from 21- 546kg/m^3 as shown in Table 7. The Olushandja treatment plant on average used more coagulant per cubic meter of water (236kg/m^3) Followed by the Ombalantu water treatment plant (115kg/m^3) then the Oshakati Water Treatment Plant (90kg/m^3) and then the Ogongo treatment plant (54kg/m^3). The differences in the amount of coagulants used per cubic meter could be attributed to a lack of equipments (jar test equipment) to determine coagulant dose and lack of maintenance at the Ombalantu treatment plant, which was automated and now dosing is done manually. The high amount of coagulant used could also be attributed to the type of coagulants used as the two plant use a different coagulant from the other two treatment plants. The amount of coagulant used per m^3 of water at all treatment plants generally decreased during winter (dry period June to October) except at the Olushandja treatment plant were increases in coagulant dosage was recorded during winter. Figure 19 shows the trends of the amount of coagulants (kg) used per m^3 at the four treatment plants along the Canal for 2006/2007.

The decrease in coagulant dose during winter could be attributed to the change in water quality, as during the dry season stream flow is composed entirely of base flow, unlike during the wet season when discharge is made up of both base flow and quick flow (Smakhtin, 2000). According to Chapman (1996) during flood periods, water quality usually shows marked variations due to different origins of the water. Surface run-off is generally highly turbid and carries large amounts of total suspended solids. Sub-surface run-off leaches dissolved organic carbon nutrients and nutrients from soils. High coagulant dosages could also be due to elevated pH and alkalinity during the rain season as more coagulants dose is needed to lower pH to reach optimal levels for organic matter removal. The increase in the amount of coagulant dose to produce a m^3 during winter at Olushandja treatment plant could be attributed to over use of chemicals, as the plant has no equipment to determine the optimum dosage.

According to Ribaudo *et al.,* (2000) increased levels of dissolved solids in public drinking water increases water treatment costs due to increased chemical required to treat the water, it also forces development of alternative water supplies and reduce the life spans of water-using household appliances.

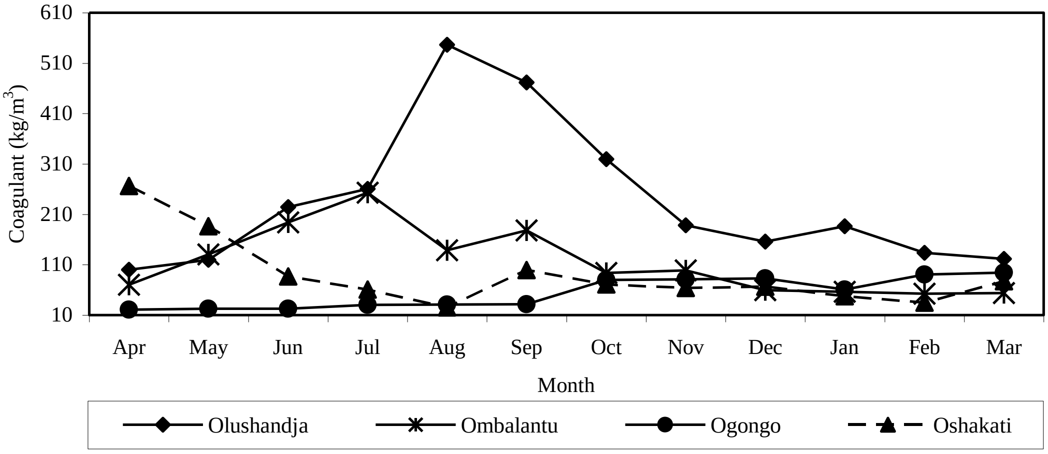

Figure 19: The amount of coagulants used per m^3 at the four treatment plants for 2006/2007

There seemed to be consensus from the workers that coagulant dosage increased during the rainy season as opposed to dry season, however this was not the case from the data analysis however acknowledgement is given to the fact that some treatment do not have proper dosage determination equipments and the breakdown of water meters and other equipments as possible source in the leading to the contradicting findings. The jar tests results carried out on water samples collected from the four treatment plant and using the same chemicals showed that chemical dosages increase from upstream to down stream and higher turbidity requires higher dosages. Table 8 presents the averages obtained from the jar tests.

Table 8: Average jar test results at the four treatment plants.

Treatment Plant	Turbidity	pH	Opt Dosage
Olushandja	132	7.74	16
Ombalantu	150	7.66	18
Ogongo	187	8.11	29
Oshakati	243	8.26	38

5.3.4. Chlorine

The minimum and maximum monthly averages of chlorine used to produce a m^3 of water at the four treatment plants were found to range from 118 - 28926 kg/m^3 as shown in Table 7. Figure 20 shows the trend in the amount of chlorine (kg) used per m^3 at the four treatment plants along the Canal for 2006/2007. The Olushandja treatment plant on average used more chlorine to produce a m^3 of water (513 kg/m^3) followed by the Oshakati treatment plant (365 kg/m^3) then the Ogongo treatment plant (312 kg/m^3) and the Ombalantu treatment plant (222 kg/m^3). The difference could be due to the water pH according to Ministry of Health (2005) the efficiency of disinfection by chlorine is strongly pH dependent. The Olushandja treatment plant recorded the highest pH values compared to the other treatment plants. The difference in the amount of chlorine used could also be attributed to the dosing efficiency and competence of personnel.

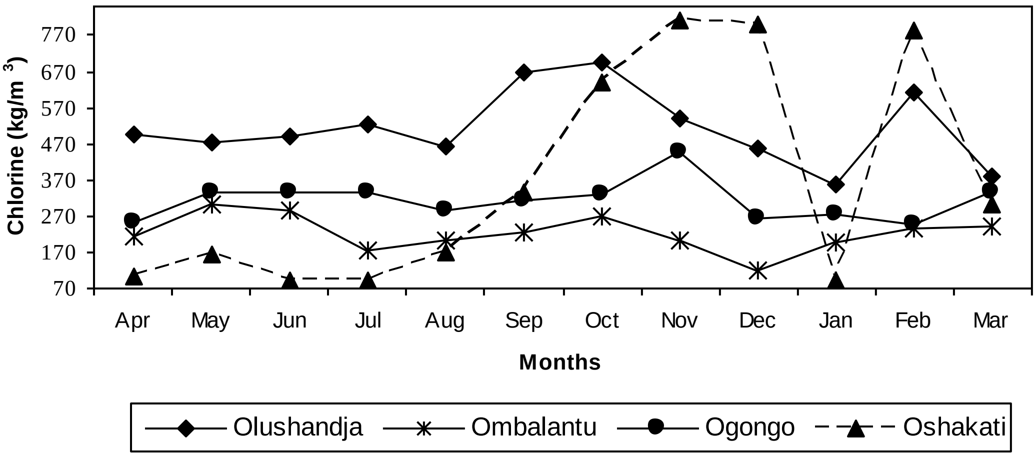

Figure 20: The amount of chlorine used per m^3 at the four treatment plants for 2006/2007

The amount of chlorine used to produce a cubic meter of water was relatively constant during winter (June-September) and increased during summer. This variation could be attributed to increased levels of particulate matter in the water. According to Ministry of Health (2005) dissolved and particulate constituents in the water consume the disinfectant, as these constituents make up the chemical disinfectant demand. The disinfectant demand is important because it is the disinfectant residual in the water, e.g. the concentration of free available chlorine, not the disinfectant dose that determines the efficacy of a disinfectant. Sufficient disinfectant must therefore be added to the water to allow for the disinfectant demand reactions to occur, and still ensure that an adequate disinfecting residual is present this leads to the increase in the amount of chlorine used.

5.3.5. Cost of chemicals

The minimum and maximum monthly averages of cost of chemical used to produce a m^3 of water at the four treatment plants were found to range from 1-58 N$/ m^3 as presented in Table 7. The Oshakati treatment plant recorded the highest average cost of chemicals per m^3 (11 N$/ m^3) followed by the Ombalantu (6 N$/ m^3) then Ogongo treatment plant (4 N$/ m^3) and the Olushsndja treatment plant (3 N$/ m^3). The differences in the cost of chemicals used per m^3 could be attributed to the cost of the respective chemicals used at the different treatment plants, determination of chemical dosages, the under estimation of the water produce due to broken water meter and the quality of water. Figure 21 shows the trends of cost of chemicals per m^3 at the four treatment plants along the Canal for 2006/2007.

The cost of chemicals at Olushandja and Ogongo treatment plant showed a consistent trend as the respective cost per m^3 ranged from 1-5 N$/ m^3 and 3-6 N$/ m^3 respectively. The Ombalantu treatment plant recorded high cost per m^3 in August this could be due to underestimation of the water produced as the water meter was out of order for ten days and over estimation could have been the reason why the cost of chemical was at its minimum in November as the water was out of order for three days. The cost of chemicals at the Oshakati treatment plant increased in August this could be attributed to use of lime that started in August. The water meter at the Oshakati treatment plant was out of order for five months from November to March 2007 which could explain the fluctuation in cost of chemicals used per m^3 especially in February and March which could be attributed to over and under estimation of the water produced.

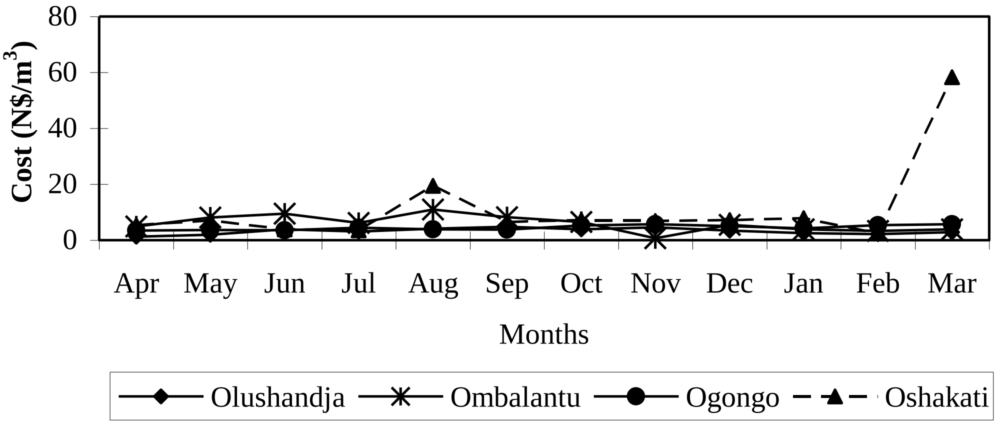

Figure 21: Average chemical cost per m^3 at the four treatment plants for 2006/2007

5.4. Intervention measures to reduce pollution

The amount of litter that collected in the Canal from March to April 2008 is presented in Table 9. The mount of plastics found in the Canal was highest in urban areas compared to village; this can be attributed to improper disposal of litter in urban set up. There was a strong dependency of plastic usage in Namibia and they are given free of charge for every purchase. Bottles and cans gets into the Canal through direct dumping since they are heavy to be carried by natural elements especially wind.

Debris affects the water quality by adding chemicals to the water. Some of the materials found in the Canal included buckets that once held paints and other solvents as well as cigarette butts which contains toxic chemicals that can impact on water quality.

Table 9: The amount of litter collected from the Canal at the three representative sites between March and April 2008.

Sampling Site	Plastics (kg)	Bottle & cans(kg)	Plant materials(kg)	Others (kg)
Village	1.1	0.9	14.2	0.4
Small town	1.6	2.3	14	0.8
Major town	1.8	0.9	14.2	0.35

The results from data collection indicate that, the water is certainly unfit for drinking purposes without any form of treatment, but for various other surface water usage purposes, it still could be considered quite acceptable. But the increasing trends in pollution loads and the amount of litter getting into the Canal is cause for concern. Because once a trend in pollution sets in, it generally accelerates to cause greater deterioration. So few years from now, serious water quality deterioration could take place. Hence appropriate measures should be taken such as:

1. Education and awareness campaigns

- From the type of litters found in the Canal there is an indication that there is little or no community awareness on water resource degradation. The utility should be active in raising awareness in the communities through various awareness campaigns and training programs.

2. Legislations

- Plastics, bottles and cans are one of the major solid wastes in the Canal; this is so partly because there is monetary value attached to them as they are obtained close to nothing. If a fee was to be charged for these items it will drastically reduce their presence in the environment. Reasons can be learned from the city of Harare in this regard.

3. Enforcement of existing regulations

- There are currently regulations concerning building or setting up of structures along the Canal, but this are not enforced as buildings and kraals are set up with in the buffer zone.

CHAPTER SIX

6. CONCLUSSION AND RECOMMENDATION

6.1. Conclusions

1. The results indicate that, the water was unfit for drinking purposes without treatment, but for various other water uses (irrigation, fisheries and stock watering) it was suitable as it was within the NAMWATER standards and WHO guidelines for drinking water and the water quality was also within the generally accepted ranges for agriculture and fisheries use.

2. The pollution load showed an increasing trend from upstream to down stream. This was attributed to the cumulative effects of pollution entering the Canal from the surrounding villages, grazing areas and urban centres through Overland flow and direct dumping into the Canal.

3. Water treatment chemical costs per m^3 were generally high at the Oshakati treatment plant (down stream) and lowest at the Olushandja treatment plant (upstream) and there is a general increase in chemical costs m^3 from treatment plants upstream to those down stream. Jar test proved that coagulant dosages increase from upstream to down stream. This could be attributed to the increase in pollution loads along the Canal from upstream to down stream.

4. Litter disposal is a serious concern as some litters found in the Canal contains potentially toxic chemicals to humans. To prevent water pollution in the Canal, community education is imperative and NAMWATER have to be at the forefront.

6.2. Recommendation

1. Water pollution control should be a subset of water resources management which entails two closely related elements, the maintenance and development of adequate quantities of water at adequate quality. Hence the need for continuous monitoring of the Canal pollution trends as part of the water resources management as enshrined in Agenda 21.

2. Community education should be the basis of achieving the IWRM and water efficiency plans set at The World Summit on Sustainable Development in 2002 which aims to reverse the current trend in water resources degradation and to achieve integrated management of land, water and living resources.

3. There is a need to establish a pollution monitoring and enforcement institution, as regulations are in place but there sis lack of enforcement.

4. All treatment plants need to be equipped with standard instruments to determine chemical dosages and maintenance and speedy repairs of equipments is vital in minimising chemical costs.

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8. APPENDICES

Appendix A: Salinity tolerance levels of crops, salinity hazard of irrigation water and sodium hazard of water based on SAR

Table 1A: Soil salinity tolerance levels1 for different the crops (Fipps, 2003)

Crop	Yield potential, TDS				Maximum TDS (mg/l)
	100%	90%	75%	50%	
Bean	1.0	1.5	2.3	3.6	22400
Groundnuts	3.2	3.5	4.1	4.9	5600
wheat	6.0	7.4	9.5	13.0	16000
Cabbage	1.8	2.8	4.4	7.0	9600
Carrot	1.0	1.7	2.8	4.6	6400
Onion	1.2	1.8	2.8	4.3	6400
Potato	1.7	2.5	3.8	5.9	8000
Tomato	2.5	3.5	5.0	7.6	10400

Table 2A: General Hazard from salinity of irrigation water (Hopkins, et al., 2007)

Water electrical conductivity (EC)	Water total dissolved solids (TDS)	Salinity hazard and effects on management
below 0.25	below 160	Very low hazard. No detrimental effects on plants, and no soil buildup expected.
0.25–0.75	160–480	Low hazard. Sensitive plants may show stress; moderate leaching prevents salt accumulation in soil.
0.75–2.0	480–1,280	Medium hazard. Salinity may adversely affect plants. Requires selection of salttolerant plants, careful irrigation, good drainage, and leaching.
2.0–3.0	1,280–1,920	Medium-high hazard. Will require careful management to raise most crops.
Above 3.0	Above 1,920	High hazard. Generally unacceptable for irrigation, except for very salt-tolerant plants where there is excellent drainage, frequent leaching, and intensive management

Table 3A: The sodium hazard of water based on SAR values (Source: Fipps 2003)

SAR values	Sodium hazard of water	Comments
1-10	Low	Use on sodium sensitive crops such as avocados Must be cautioned.
10 - 18	Medium	Amendments (such as Gypsum) and leaching needed
18 - 26	High	unsuitable for continuous use
> 26	Very High	Generally unsuitable for use

Appendix B: NAMWATER standards for bacteriological, determinants with aesthetic/physical implications and for stock watering (NAMWATER, 2008)

Table 1B: NAMWATER standards for bacteriological parameters

DETERMINANTS (COUNTS)	LIMITS FOR GROUPS			
	A**	B**	C	D*
Standard plate counts per 1 ml	100	1000	10000	10000
Total coliform counts per 100 ml	0	10	100	100
Faecal coliform counts per 100 ml	0	5	50	50
E. coli counts per 100 ml	0	0	10	10

Table 2B: NAMWATER standards for determinants with aesthetic/physical implications

DETERMINANTS	UNITS	LIMITS FOR GROUPS			
		A	B	C	D*
Colour	mg/l Pt**	20	-	-	-
Conductivity	mS/m 25^0C	150	300	400	400
Total hardness	mg/l $CaCO_3$	300	650	1300	1300
Turbidity	N.T.U.***	1	5	10	10
Chloride	mg/l Cl	250	600	1200	1200
Chlorine (free)	mg/l Cl	0.1-5.0	0.1-5.0	0.1-5.0	5.0
Fluoride	mg/l F	1.5	2.0	3.0	3.0
Sulphate	mg/l SO_4	200	600	1200	1200
Copper	µg/l Cu	500	1000	2000	2000
Nitrate	mg/l N	10	20	40	40
Hydrogen Sulphide	µg/l H_2S	100	300	600	600
Iron	µg/l Fe	100	1000	2000	2000
Manganese	µg/l Mn	50	1000	2000	2000
Zinc	mg/l Zn	1	5	10	10
pH****	pH-unit	6.0-9.0	5.5-9.5	4.0-11.0	4.0-11.0
Magnesium	mg/l Mg	70	100	200	200
	mg/l $CaCo_3$	290	420	840	840
Sodium	mg/l Na	100	400	800	800

Table 3B: NAMWATER standards for stock watering

Determinants	Concentrations
pH	< 4.0 and > 11.0
Conductivity	> 895.5 mS/m
TDS	> 6000 mg/l
Na	>2000 mg/l
K	>1200 mg/l
SO^4	>1500 mg/l
NO_3 and NO_2	> 110 mg/l
F	> 6.0 mg/l
Cl	> 3000 mg/l
Total Hardness	>2800 mg/l
Ca	> 2500 mg/l
Mg	>2057 mg/l

* **All values greater than the Figure indicated.**
** **Pt = Platinum Units.**
*** **Nephelometric Turbidity Units.**
**** The pH limits of each group exclude the limits of the previous group

Appendix C: Field Data Sheet for water sample collection

Sapling Location---

Sampling Point--

Date of Sampling--

Time of Sampling---

Contact Person--

Telephone number---

Sample Source -----------------

ON-SITE OBSERVATION

a) Odour
----- Present
----- Absent

b) Colour
------ Present
------ Absent

Comments on Appearance of Water ---

Weather
Sunny------------------
Rainy--------------------
Cloudy------------------
Windy------------------

General Comments____

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Appendix D: Water Treatment Plant-Performance Report for 2006/07.

(Cuvelai Area) - (Olushandja) Water Treatment Plant - Performance Report - 2006/07 Financial Year												
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Raw Water - Average Analysis												
Turbidity (NTU)	138	59	24	20	21	22	24	38	75	45	29	16
pH	10	9	10	11	11	11	11	11	12	11	11	11
Coagulant (mg/l)	10	8	4	4	2	2	3	5	6	5	7	8
Aluminium (mg/l)	202	156	81	8	73	75	84	85	110	116	165	86
Int-chlorination (mg/L)	2	2	2	2	2	2	1	2	2	3	2	3
Water Production (m^3)	41386	41110	41283	45434	50826	53918	58080	54808	52680	61239	51094	45065
Coagulant (kg)	414	343	184	174	93	114	182	292	338	329	382	370
Aluminium (kg)	8369	6397	3363	378	3695	4047	4877	4673	5784	7101	8431	3871
Int-chlorination (kg)	84	87	84	86	110	81	84	102	116	172	84	118
Cost of Chemicals (N$)	33169	21449	10492	15001	12257	11159	14891	12040	15342	23817	24003	15737
Coagulant(kg/m3)	100	120	224	260	546	472	319	188	156	186	134	122
Aluminium (kg/m3)	5	6	12	120	14	13	12	12	9	9	6	12
Int-chlorination (kg/m3)	495	474	493	526	463	667	694	538	455	356	610	382
Chemicals Cost (N$/$m^3$)	1	2	4	3	4	5	4	5	3	3	2	3

(Cuvelai Area) - (Ombalantu) Water Treatment Plant - Performance Report - 2006/07 Financial Year												
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Turbidity (NTU)	191	112	35	34	22	28	34	42	68	43	31	34
pH	8	9	9	9	7	8	7	8	8	8	7	8
Coagulant (mg/l)	14	8	5	4	7	6	11	10	17	18	19	19
Int-chlorination (mg/L)	5	3	4	6	5	4	4	5	8	5	4	4
Raw Water Intake (m^3)	28716	42109	38101	35402	31842	37098	40213	36752	41469	38807	34228	40614
Coagulant (kg)	408	323	197	140	230	208	430	371	695	686	653	755
Chlorine (kg)	134	139	134	202	155	165	149	183	351	197	146	169
Cost of Chemicals (N$)	5888	5182	4008	5790	2904	4537	6221	56980	7570	9957	10341	10468
Coagulant (kg/m3)	70	130	194	253	139	178	93	99	60	57	52	54
Chlorine (kg/m3)	214	304	284	175	205	225	270	201	118	197	235	241
Chemicals Cost (N$/$m^3$)	5	8	10	6	11	8	6	1	5	4	3	4

(Cuvelai Area) - (Ogongo) Water Treatment Plant - Performance Report - 2006/07 Financial Year												
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Turbidity (NTU)	188	104	50	38	39	37	32	36	45	44	42	31
pH	8	9	8	9	8	9	8	9	9	9	8	9
Coagulant (mg/l)	48	44	44	33	32	32	13	12	12	16	11	11
Post-chlorination(mg/L)	4	3	3	3	4	3	3	2	4	4	4	3
Raw Water Intake (m^3)	236425	262040	232588	244058	230290	220928	218704	221971	290615	252383	209679	221517
Coagulant (kg)	11348	11530	10234	8054	7454	6964	2742	2747	3504	4157	2317	2344
Chlorine (kg)	946	786	698	732	806	707	660	500	1097	911	848	665
Cost of Chemicals (N$)	69828	71569	66231	55294	59102	59202	41352	38835	58139	59468	39256	39023
Coagulant (kg/m3)	21	23	23	30	31	32	80	81	83	61	90	95
Chlorine (kg/m3)	250	333	333	333	286	313	331	444	265	277	247	333
Chemicals Cost (N$/$m^3$)	3	4	4	4	4	4	5	6	5	4	5	6

(Cuvelai Area) - (Oshakati) Water Treatment Plant - Performance Report - 2006/07 Financial Year												
	Apr	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**
Turbidity (NTU)	231	283	50	38	30	28	72.2	63	27	307	178	362
pH	7	8	8	8	9	9	9	9	8	8	9	8
Coagulant (mg/l)	4	5	12	17	40	10	14	16	15	21	29	13
Post-chlorination(mg/L)	10	6	11	11	6	3	2	1	1	11	1	3
Raw Water Intake (m3)	865409	811960	689664	662180	723139	787528	711806	683543	710070	787258	731565	744297
Coagulant (kg)	3254	4360	7979	10926	28926	7907	10065	10663	10736	16509	21223	9668
Chlorine (kg)	8282	4969	7607	7211	4259	2363	1110	841	888	8313	936	2471
Cost of Chemicals (N$)	162587	114295	179097	189805	37196	120911	99043	99423	98472	99543	306721	12781
Coagulant (kg/m3)	266	186	86	61	25	100	71	64	66	48	34	77
Chlorine (kg/m3)	104	163	91	92	170	333	641	813	800	95	781	301
Chemicals Cost (N$/$m^3$)	5	7	4	3	19	7	7	7	7	8	2	58

Appendix E: Field Data Sheet for rubbish collection

Sapling Location --

Sampling Point --

Date of Sampling--

Weather
Rainy------ ---------
Windy--------------

General comments ____
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Category of rubbish	**Weight (kg)**
Plastics	
Bottles	
Plant material	
Household goods	
other	