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

M. K. Shuuya and Z. Hoko

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

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

Introduction

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

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

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

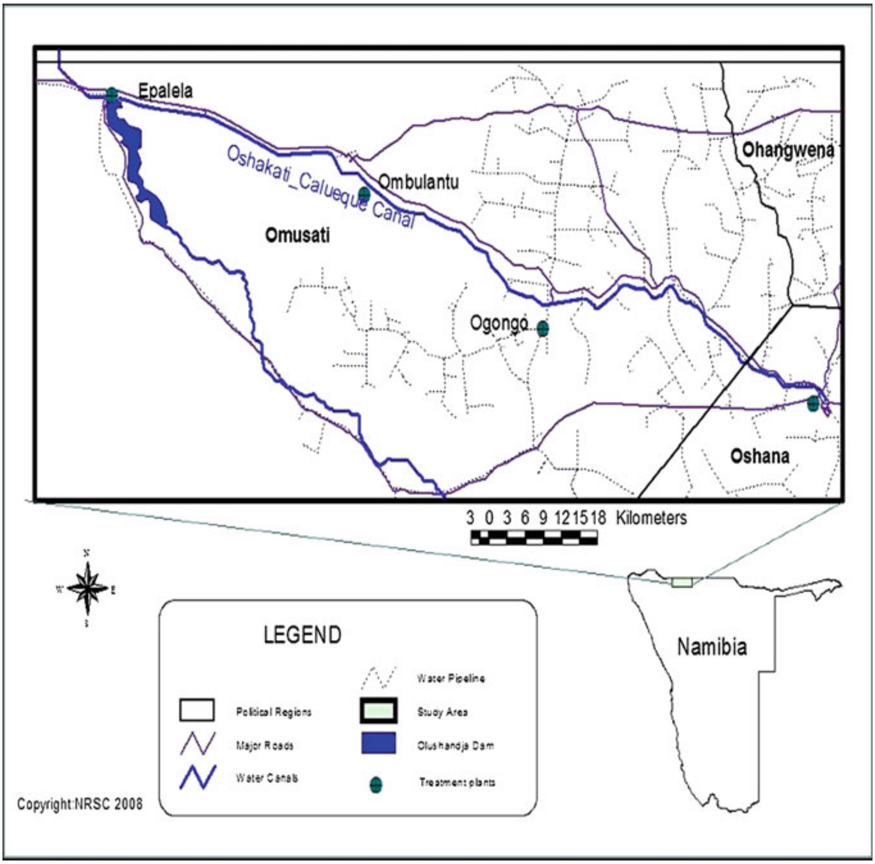


Fig. 3.1 Map of Namibia showing the study area (Map was prepared for the author by Natural Remote Sensing Center of the Namibian Ministry of Agriculture, Water and Forestry)

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

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

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

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

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

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

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

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

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

Study Design

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

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

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

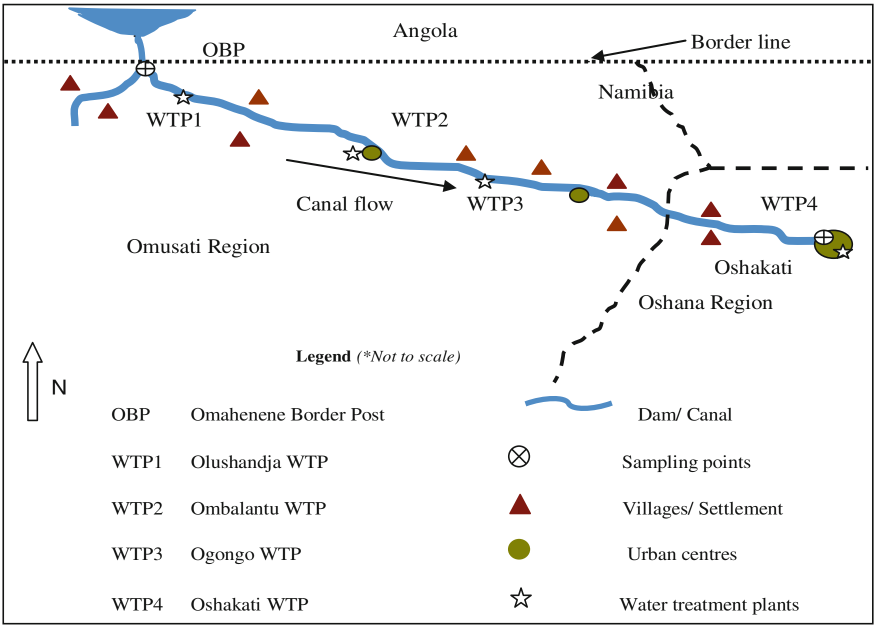


Fig. 3.2 Sampling points near OBP and near OWTP and water treatment plants

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

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

Results and Discussion

Water Quality trends in the canal

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

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

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

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

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

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

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

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

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

Effect of Pollution on the Water Purification Process

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

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

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

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

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

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

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

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

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

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

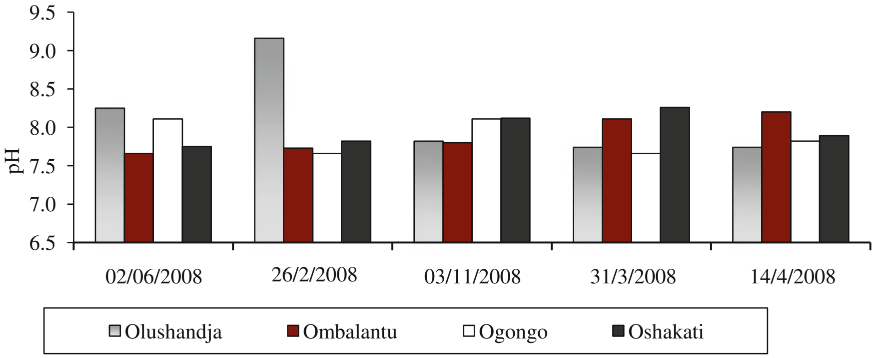


Fig. 3.3 pH values for raw water at the four treatment plants in the period February–April 2008

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

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

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

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

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

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

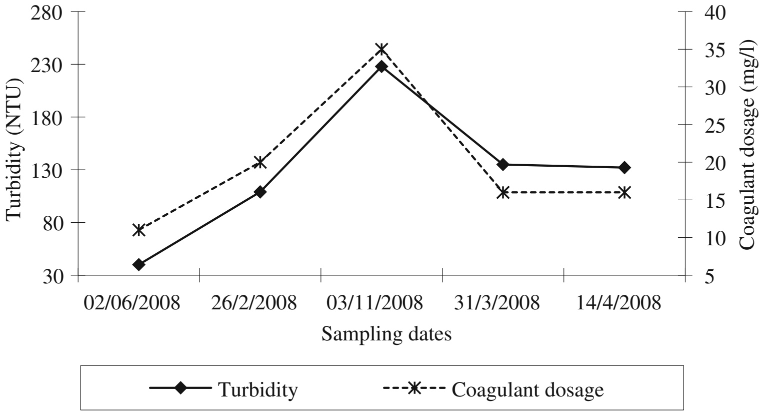


Fig. 3.4 Experimental turbidity and coagulant dosage trends at the Olushandja treatment plant from February to April 2008. (*bold line* on plot-turbidity; *dotted line* on plot-coagulant dose)

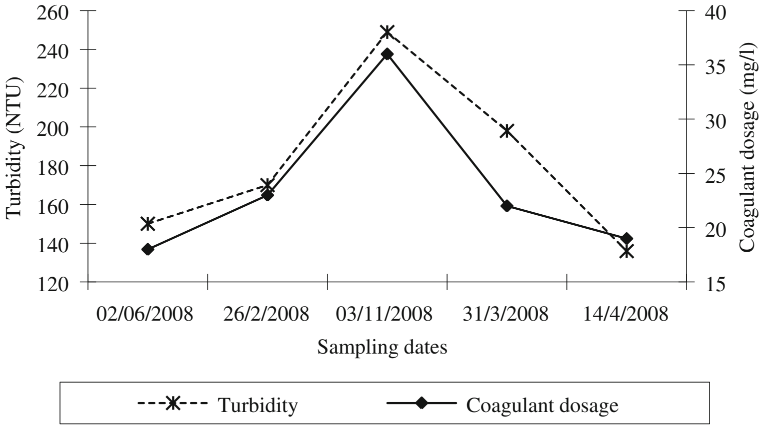


Fig. 3.5 Experimental turbidity and coagulant dosage trends at Ombalantu treatment plant from February to April 2008

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

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

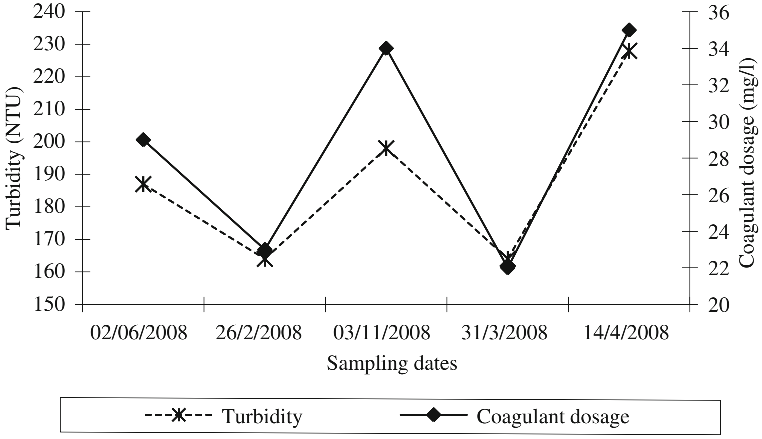


Fig. 3.6 Experimental turbidity and coagulant dosage trends at Ogongo treatment plant from February to April 2008

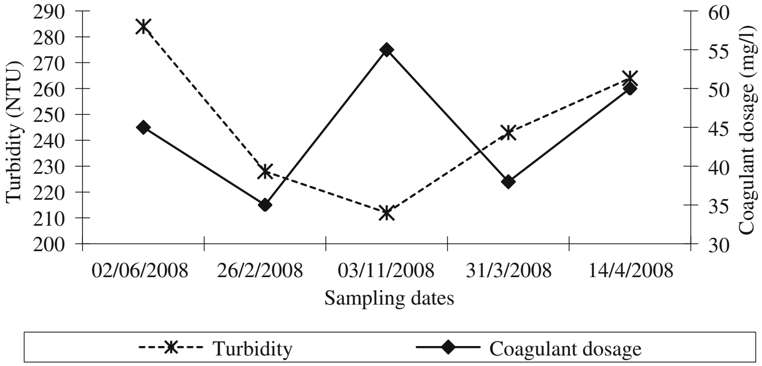


Fig. 3.7 Experimental turbidity and coagulant dosage at the Oshakati treatment plant from February to April 2008

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

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

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

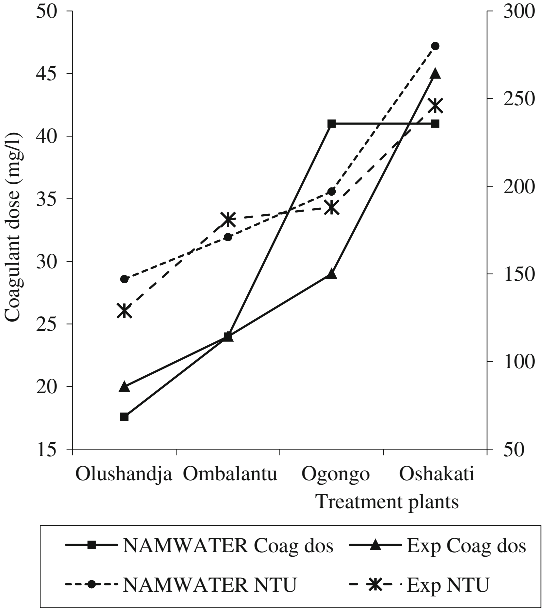
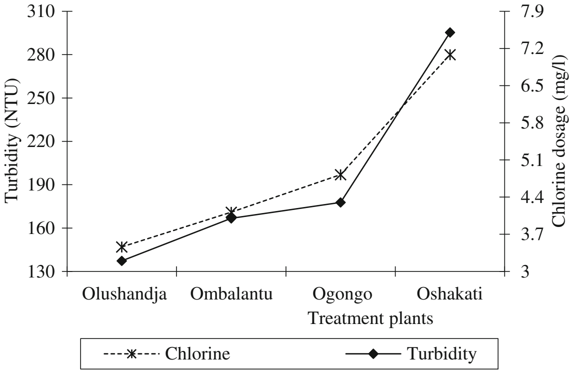


Fig. 3.9 Trends in turbidity and chlorine dosage at the four treatment plants from February to April 2008 based on NAMWATER records



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

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

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

Results in this table are based on NAMWATER records

[a] *For the slow sand filter plant, backwashing is done for the roughing filters which precede the slow sand filters. See* Chap. 2

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

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

Conclusions

Three main conclusions can be drawn:-

(1) There was an increasing trend for all parameters studied for the canal from upstream to downstream sampling points along the canal. The increase in concentration was attributed to pollution of the canal as a result of the human activities and runoff in the basin.

(2) The pollution in the canal increased chemical requirements for coagulation and disinfection from upstream to downstream of the canal and also affected the operation of the plants in terms of backwashing as the frequency generally increased from upstream to downstream treatment plants along the canal.

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

Recommendations

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

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