

# Changes in water quality in the Owabi water treatment plant in Ghana

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**Abstract** The study was conducted on the status of the quality of water from the Owabi water treatment plant that supplies drinking water to Kumasi, a major city in Ghana, to ascertain the change in quality of water from source to point-of-use. Physico-chemical, bacteriological water quality parameters and trace metal concentration of water samples from five different treatment points from the Owabi water treatment plant were investigated. The raw water was moderately hard with high turbidity and colour that exceeds the WHO guideline limits. Nutrient concentrations were of the following order:  $\text{NH}_3 < \text{NO}_2^- < \text{NO}_3^- < \text{PO}_4^{3-} < \text{SO}_4^{2-}$  and were all below WHO permissible level for drinking water in all the samples at different stages of treatment. Trace metal concentrations of the reservoir were all below WHO limit except chromium (0.06 mg/L) and copper (0.24 mg/L). The bacteriological study showed that the raw water had total coliform (1,766 cfu/100 mL) and faecal coliform (257 cfu/100 mL) that exceeded the WHO standard limits, rendering it unsafe for domestic purposes without treatment. Colour showed strong positive correlation with turbidity ( $r = 0.730$ ), TSS ( $r \geq 0.922$ ) and alkalinity (0.564) significant at  $p < 0.01$ . The quality of the treated water indicates that colour, turbidity, Cr and Cu levels reduced and fall within the WHO permissible limit for drinking water. Treatment process at the water treatment plant is adjudged to be good.

**Keywords** Water quality · Treatment process · Owabi · Bacteriological · Physico-chemical

## Introduction

Water resources support all forms of life including human beings. Though water is available on earth in huge quantities, only about 3 % is available as freshwater in the universe, and among the fresh water only about 5 % is available for human consumption (Postel et al. 1996; Usharani et al. 2010). The importance of water to humans is underscored by the fact that many great civilizations in the past sprang up along or near water bodies. Development of water resources has, therefore, been used as a yardstick for socio-economic and health status of many nations worldwide (Karikari and Ansah-Asare 2006).

Freshwater ecosystems consist of producers, consumers and decomposers (bacteria and fungi). Their interactions with light, water, dissolved nutrients and suspended solids determine the quality of water in the ecosystem (Du et al. 2014; Kolpin et al. 2002). Water quality problems have increased in recent years in response to growth of human population and increase in industries along water bodies.

Due to anthropogenic activities, freshwater systems worldwide are confronted with numerous xenobiotics and are overloaded with nutrients. Polluted water is an important vehicle for the spread of diseases. In developing countries 1.8 million people, mostly children, die every year as a result of water-related diseases (Karikari et al. 2007; WHO 2004a, b). A major contribution to chemical contamination originates from domestic and industrial wastewater discharges containing both organic and inorganic contaminants that negatively impact water quality (Gao et al. 2010; Kolpin et al. 2004; Snyder et al. 2001).

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Contamination may also come from agricultural activities in which millions of tons of fertilizers and pesticides are employed annually (Schriks et al. 2010). Nitrates ( $\text{NO}_3^-$ ) and phosphates ( $\text{PO}_4^{3-}$ ) are common pollutants associated with fertilizers. Pollution and contamination from such sources manifests itself in the form of increased acidity and higher concentrations of nutrients, sediments, salts, trace metals, chemicals and other toxins, as well as harmful pathogenic organisms that may thrive in warmer waters (United Nations 2009).

In terms of microbial water quality, wide variety of viruses, bacteria and protozoan in water are of concern. These micro-organisms have mostly been associated with diseases such as gastrointestinal disorders as well as eye, skin and nose infections (DWAf 1996; Germs et al. 2004).

Metals such as Cr, Mn, Co, Cu, Fe and Zn play biochemical roles in the life processes of aquatic plants and animals, and their presence in trace amounts in the aquatic environment is essential. However, at relatively high concentrations ( $>1$  mg/L), these metals become toxic (Nurnberg 1982). A special feature of these metals is that they are not biodegradable. Instead, they go through a biogeochemical cycle with substantially long residence times in the various spheres of the environment. Within this cycle they eventually end up in the human food chain. Metals constitute a particular risk to human health because they can accumulate in vital organs of man (Nurnberg 1982) and exert progressively growing toxic actions over long periods of exposure (Akoto et al. 2008). Chemicals such as pesticides, PCBs, PBDEs, furans and toxins (e.g., from cyanobacteria) affect humans directly or bioaccumulate in fish and organisms consumed by humans, causing developmental and neurological damage. Every year over a million people die from diarrhoeal disease attributable to consumption of unsafe water or poor sanitation and hygiene. More than half of these are children under 5 who are more at risk from diarrhoea (WHO 2004b).

Water supply is one of the key natural resources that are inevitable for sustainability of human and environmental health (Marobhe et al. 2007). The adverse impacts of poor water supply have long been recognized in both developing and developed countries and take the form of outbreaks of diseases (Esrey et al. 1991; Ford 1991; Payment and Hunter 2001).

Water distribution systems play a pivotal role in preserving and providing quality water to the public (Faroq et al. 2008). Drinking water quality deteriorates during collection and storage (Andrew et al. 2005) as well as in distribution networks (Lehtola et al. 2004; Karavoltzos et al. 2008). It, therefore, becomes imperative to monitor water quality at each stage of treatment. Surveillance of drinking water quality (SDWQ) is the continuous and vigilant public health assessment and overview of the

safety and acceptability of drinking water supplies (WHO 2004a). SDWQ is instituted to minimize the incidence of chemical and biological toxicity and to boost consumer confidence in the water they use (Leeuwen 2000).

Ghana's water resources have been under increasing threat of pollution in recent years due to rapid demographic changes, which have coincided with the establishment of human settlements lacking appropriate sanitary infrastructure. This applies especially to peri-urban areas, which surround the larger metropolitan towns. People living in these areas often utilize contaminated surface water for drinking, recreation and irrigation (Verma and Srivastava 1990).

The Owabi reservoir provides drinking water to part of Kumasi metropolis and its environs (Akoto et al. 2008). The functions of the Owabi catchment which include maintenance of water quality, water storage, water recharge, reproduction area for fish and other aquatic organisms and climate control can adversely be affected by high population and associated increase in human activities (Okurut et al. 2000).

It is widely perceived that human activities within the catchment may be impacting negatively on the quality of water and other resources such as fish and food derived from the area. The rivers within the catchment also serve as sinks for industrial and domestic wastes. Pollution of the water bodies and the accompanying depletion of their resources can put the lives of humans and aquatic organisms, which depend on these rivers in danger (Akoto et al. 2010). Unfortunately, there is little information on the impact of human activities on the quality of water within the catchment. The purpose of this study was to assess the changes in quality of water from source through treatment to the storage facility of the Owabi water treatment plant. Data obtained from this research will be vital for policy makers in the implementation of responsible water quality regulations, for characterizing and remediating contaminations and for the protection of the health of humans and aquatic organisms.

## Materials and methods

### Study area

The Owabi reservoir is situated on latitude  $06-43^\circ$  N and longitude  $01-36^\circ$  N with altitude 287 m. It is located at Owabi near Akropong Esaase in the Atwima Mponua district of the Ashanti region. It was constructed in 1928. The main river is the Owabi river with seven tributaries coming together to form the reservoir. The average area of the entire reservoir is  $3.5 \text{ km}^2$  with average depth of 6.86 m when spilling. It has a capacity of 13.7 billion

gallons of water. The Owabi reservoir is designed to produce 20 % of the total potable water requirement in the Kumasi metropolis and nearby townships (Akoto et al. 2010). The functions of the Owabi catchment which include maintenance of water quality, water storage, water recharge, reproduction area for fish and other aquatic organisms and climate control can adversely be affected by high population and associated increase in human activities (Okurut et al. 2000).

The water treatment plant is built near the reservoir which provides about 3 million gallons of potable water to the Kumasi Metropolis per day. The surrounding land of the study area can be demarcated into four categories: agriculture, human settlement, vegetation cover and water bodies. The catchment area is densely populated because of rapid urbanization and agricultural growth during the past few decades. The river and its tributaries within the catchment run through some communities within the Kumasi Metropolis. The main sources of water pollution include municipal waste from suburbs like Kronum, Bremang and Abrepo that are situated within the catchment as well as industrial effluents from small-scale industries dotted along the tributaries (Akoto et al. 2010).

#### Water sampling

Samples were collected from the reservoir (RSV), sedimentation tank (MDT), filtered water tank (MDT1), disinfected water (AFT) and from distribution points (DST) of consumers for a period of 5 months (between December 2011 and April 2012) during the dry season during which the dynamics of the reservoir do not change drastically due to low downpour. Water samples were collected with plastic containers previously cleaned by washing with non-ionic detergents then rinsed with tap water and later soaked in 10 % HNO<sub>3</sub> for 24 h and finally rinsed with de-ionized water and air dried prior to usage. At the point of sampling sample containers were rinsed with sample water three times before filling. The samples were labelled, stored in an ice-box and transported to the laboratory. They were stored in the refrigerator at 4 °C prior to analysis. Water samples for bacteriological analysis were collected into pre-sterilized 500 mL stoppered glass bottles. Test for bacteria in the samples was conducted within 6 h after sampling. All samples were kept in a cool box (8–10 °C) immediately after collection and transported to the laboratory on the same day.

#### Laboratory analysis

The pH meter (Model 3150 JENWAY), digital conductivity meter and Hanna instrument; LP 2000 turbidimeter were calibrated appropriately and used to measure the pH,

EC and TDS and turbidity, respectively. The electrodes of the above-mentioned meters were immersed in the samples. They were allowed to stabilize and their readings recorded.

Calcium and total hardness were determined by EDTA titration method. Ammonium chloride in concentrated ammonia was used to buffer the samples with Erichrome Black T as indicator for total hardness, whereas in calcium hardness NaOH was the buffer and murexide the indicator. Magnesium hardness was calculated from the difference between the total hardness and the calcium hardness which is expressed in mg/L.

Alkalinity was measured by titration with H<sub>2</sub>SO<sub>4</sub>. Phenolphthalein was added to the samples and titrated against standard H<sub>2</sub>SO<sub>4</sub> until the pink colour disappeared. Methyl orange is added and titration continued until the appearance of first permanent pink colour. Chloride concentration was by Argentometric titration using standard AgNO<sub>3</sub>. Potassium chromate was employed as the indicator and titration continued until colour changed from yellow to brick-red.

Colourimetric method was employed in the determination of the nitrite concentration in the samples. Griess-Ilosvay's solution No. 1 and Solution No. 2 were added to the samples. The mixture was swirled gently and allowed to stand for 15 min. The mixture was transferred into a Nessler's tube. The colour was compared with the standard colours of the nitrite disc. The value of the matching colour was read using the nitrite disc and comparator.

The Palintest Photometer 5000 (Manitoba, Canada) was used in the determination of metals (Cr, Mn, Cu, Zn, K, Al and Fe) as well as SO<sub>4</sub><sup>2-</sup>, PO<sub>4</sub><sup>3-</sup>, NO<sub>3</sub><sup>-</sup>, NH<sub>3</sub> and F<sup>-</sup> concentrations. Analytical water test tablets (photometer grade) reagents for specific test were used for the preparation of all sample solutions. The tablets were added to the samples to form complexes with the analyte which impart colour to the water. The required wavelength for the specific test was selected by moving the slide control. Distilled water was used to zero the instrument. The ON button was pressed and kept depressed until the display reads 100 (100 % T). The samples were immediately submitted to the instrument to read the % transmittance. The displayed reading was taken to a calibration chart from which the concentration of the analyte is determined from the read % transmittance.

Serial dilutions of the water samples of 10<sup>-1</sup> to 10<sup>-5</sup> were prepared by measuring 1 mL of the sample into 9 mL sterile distilled water. One millilitre aliquots from each of the dilutions were inoculated into 5 mL of MacConkey Broth with inverted Durham tubes and incubated at 35 and 44 °C for total coliform and faecal coliform, respectively, for 18–24 h. Tubes showing colour change from purple to yellow and gas collected in the Durham tubes after 24 h were identified as positive for Total Coliform and Faecal

**Table 1** The mean, standard error of the mean and the range of the physico-chemical properties of the water samples from the Owabi headworks ( $n = 5$ )

Parameters	RSV	MDT	MDT 1	AFT	DST	WHO limits (WHO 2004a, b)
<b>pH</b>						
Mean $\pm$ SE	7.14 $\pm$ 0.16	6.85 $\pm$ 0.08	6.80 $\pm$ 0.13	6.88 $\pm$ 0.134	6.92 $\pm$ 0.11	6.5–8.5
Range	6.8–7.74	6.59–7.13	6.48–7.14	6.60–7.37	6.61–7.58	–
<b>Temperature (<math>^{\circ}</math>C)</b>						
Mean $\pm$ SE	26.62 $\pm$ 0.48	26.28 $\pm$ 0.62	26.52 $\pm$ 0.58	26.62 $\pm$ 0.61	26.53 $\pm$ 0.33	
Range	25.7–28.4	25.1–28.6	25.0–28.6	25.5–28.9	25.7–28.5	
<b>Colour (Hz)</b>						
Mean $\pm$ SE	66.80 $\pm$ 16.71 <sup>a</sup>	59.20 $\pm$ 24.77	12.60 $\pm$ 2.82 <sup>b</sup>	16.20 $\pm$ 3.43	15.30 $\pm$ 3.13 <sup>c</sup>	15
Range	30–115	17–150	7–22	7–26	0–30	
<b>Turbidity (NTU)</b>						
Mean $\pm$ SE	6.30 $\pm$ 1.96 <sup>a</sup>	3.77 $\pm$ 0.53	1.01 $\pm$ 0.16 <sup>b</sup>	1.10 $\pm$ 0.17 <sup>c</sup>	0.95 $\pm$ 0.20 <sup>d</sup>	5
Range	2.66–13.89	1.82–4.77	0.56–1.52	0.63–1.59	0.33–2.05	
<b>Conductivity (<math>\mu</math>S/cm)</b>						
Mean $\pm$ SE	324.40 $\pm$ 17.98	328 $\pm$ 22.98	327.40 $\pm$ 19.69	329.60 $\pm$ 22.08	331.90 $\pm$ 13.48	1,000
Range	277–365	256–368	265–375	258–371	263–379	
<b>TDS</b>						
Mean $\pm$ SE	196.60 $\pm$ 11.36	199.22 $\pm$ 14.74	198.54 $\pm$ 12.54	201.26 $\pm$ 14.33	202.03 $\pm$ 8.62	1,000
Range	166.2–219	153.6–225	159–223	154.8–230	157.8–230	
<b>TSS</b>						
Mean $\pm$ SE	7.60 $\pm$ 3.23 <sup>a</sup>	6.00 $\pm$ 2.40	1.40 $\pm$ 0.93	1.60 $\pm$ 0.40	1.10 $\pm$ 0.28 <sup>b</sup>	–
Range	3–20	2–15	0–5	1–3	0–2	
<b>Total hardness</b>						
Mean $\pm$ SE	81.20 $\pm$ 2.06	88.00 $\pm$ 8.10	86.40 $\pm$ 4.83	86.40 $\pm$ 2.48	90.00 $\pm$ 3.27	500
Range	76–88	76–120	76–100	80–92	80–114	
<b>Calcium hardness</b>						
Mean $\pm$ SE	75.20 $\pm$ 1.86	72.40 $\pm$ 3.37	73.60 $\pm$ 4.21	65.40 $\pm$ 1.78	72.20 $\pm$ 2.93	–
Range	70–80	64–84	62–88	60–70	58–84	
<b>Magnesium hardness</b>						
Mean $\pm$ SE	6.00 $\pm$ 2.09	15.60 $\pm$ 5.67	12.80 $\pm$ 3.67	21.00 $\pm$ 3.74	17.80 $\pm$ 4.58	–
Range	2–12	6–26	6–26	10–32	6–56	
<b>Alkalinity</b>						
Mean $\pm$ SE	138.60 $\pm$ 4.26 <sup>a</sup>	121.80 $\pm$ 5.39	106.80 $\pm$ 6.56 <sup>b</sup>	105.60 $\pm$ 6.97 <sup>c</sup>	103.40 $\pm$ 5.52 <sup>d</sup>	200
Range	126–150	102–132	88–120	82–120	72–128	

All parameters are in mg/L unless stated otherwise

SE standard error of the mean

a, b, c, d Denote different means

coliform. Counts per 100 mL were calculated from most probable number (MPN) tables (APHA, 1999).

#### Statistical analysis

Univariate analysis of variance was performed to establish whether differences exist within the means. Pearson's rank correlation was used to establish relationships between parameters. All tests were two-tailed. The analyses were executed by SPSS (version 16.0 for windows 2007).

#### Results and discussion

The mean, standard error of the mean and range of the physico-chemical parameters measured in the water samples at the different treatment points are presented in Table 1. The raw water had a mean pH of  $7.14 \pm 0.16$ . This is slightly higher than the pH observed for the settled and filtered water which had mean values of  $6.85 \pm 0.09$  and  $6.80 \pm 0.13$ , respectively. The pH increased slightly from  $6.88 \pm 0.13$  in the filtered water to  $6.92 \pm 0.11$  the

treated and the distributed water. Even though there were slight changes in pH as the water moved through the various treatment points, these changes were not statistically significant ( $p > 0.05$ ). This shows that the various treatment procedures do not impact significantly on the pH. The pH of the treated water in the distribution chamber falls within the WHO limits of 6.5–8.5 recommended for drinking water (WHO 2004a). The changes in pH may be due to the aluminium sulphate added to effect flocculation. Aluminium sulphate is an acid salt and reacts with the alkalinity present in the water to lower the pH. The reported pH is slightly lower than the 7.05–7.84 reported by Barbooti et al. (2010) in their work on drinking water from Baghdad.

The mean temperatures of the raw, settled, filtered, treated and distributed water are  $26.62 \pm 0.48$ ,  $26.28 \pm 0.62$ ,  $26.52 \pm 0.58$ ,  $26.62 \pm 0.61$  and  $26.53 \pm 0.33$  °C, respectively. There is no significant difference in the temperatures recorded for the water samples ( $p > 0.05$ ). Increase in water temperature decreases gas solubility and increases the photosynthetic rate of algae and aquatic plants leading to increased plant growth and algal blooms (UNEP 2008; Usharani et al. 2010). A change in water temperature can affect the general health of aquatic organisms. In too hot or too cold temperatures, organisms become stressed, lowering their resistance to diseases and pollutants (Deas and Lowney 2000; UNEP 2008). The temperature of the untreated water ( $26.62 \pm 0.48$  °C) is the optimal for supporting aquatic life. Alabaster and Lloyd (1980) reported that temperature of natural inland waters in the tropics generally varies between 25 and 35 °C. This agrees well with the 26.3–30.4 °C reported by Zabbey (2002) and 25.9–32.4 °C reported by Ansa (2005).

The untreated water had a mean colour of  $66.80 \pm 16.71$  Hz. The settled water had a mean colour of  $59.20 \pm 24.766$  Hz. The filtered water recorded a drop in colour with a mean value of  $12.60 \pm 2.821$  Hz, while samples from the treated and the distribution water recorded mean colour of  $16.20 \pm 3.43$  and  $15.30 \pm 3.13$  Hz, respectively. There was a significant difference between colour of the raw water and that of the treated water ( $p < 0.05$ ). This indicates that colour significantly reduced to acceptable levels during treatment. Colour was not affected significantly during distribution since no significant variations were recorded between treated samples and samples for the distribution system ( $p > 0.05$ ). Colour in water is usually due to the presence of inorganic ions (such as iron and manganese), humus and peat materials, plankton and weeds. The treatment processes including flocculation, sedimentation and filtration resulted in the reduction of colour in the samples.

Mean turbidity values were  $6.30 \pm 1.96$  NTU,  $3.77 \pm 0.53$  NTU,  $1.01 \pm 0.157$  NTU,  $1.10 \pm 0.16587$

NTU and  $0.9540 \pm 0.199$  NTU for the untreated, settled, filtered, treated and distributed water, respectively. The turbidity changed significantly from the raw water to the filtered water ( $p < 0.05$ ). The processes of flocculation, sedimentation and filtration reduced, significantly, the turbidity of the raw water to acceptable levels (5 NTU) as prescribed by WHO (2004a, b).

High turbidity in water causes problems with water purification processes and leads to increased treatment cost (DWAF 1998). Turbid water is often microbiologically contaminated because it is difficult to disinfect water properly (DWAF 1998). That happens because the adsorptive characteristics of some colloids and solids may shield organisms from the disinfectant. Soil erosion and run-off from the catchments could be the source of high turbidity in the raw water. There was no significant change in turbidity between the treated water and distributed water ( $p > 0.05$ ). The turbidity determined for this work is lower than 3.25–72.50 NTU reported by Akoto and Adiyiah (2007) but agrees well with that reported by Jafari et al. (2008).

Electrical conductivity (EC) recorded a mean of  $324.40 \pm 17.98$   $\mu\text{S}/\text{cm}$  for the raw water. The settled water had a mean EC of  $328 \pm 22.98$   $\mu\text{S}/\text{cm}$ . Filtered water recorded  $327.40 \pm 19.69$   $\mu\text{S}/\text{cm}$  and the treated water had mean EC of  $329.60 \pm 22.08$   $\mu\text{S}/\text{cm}$ . The distributed water recorded mean EC of  $331.90 \pm 13.48$   $\mu\text{S}/\text{cm}$ . There was no significant change in EC in the water sampled at the different sites ( $p > 0.05$ ). This means that the treatment processes did not impact significantly on EC. The average EC of typical, unpolluted rivers is 350  $\mu\text{S}/\text{cm}$  (Koning and Roos 1999). The change in EC had strong correlation with total dissolved solids (TDS) ( $r = 0.984$ ) at the 0.01 level. The EC of water, like TDS, is an indicator of total salt content of the water (Oluoyemi et al. 2010). High salt content decreases palatability of water and causes intestinal irritation in humans as well as laxative effects (WHO 1997). The EC recorded for this work is lower than the 705.67–976  $\mu\text{S}/\text{cm}$  found by Jafari et al. (2008).

TDS is a common indicator of polluted waters (Tay 2007). The mean levels of TDS measured in the samples were  $196.60 \pm 11.36$  mg/L for the raw water,  $199.22 \pm 14.74$  mg/L, for the settled water,  $198.54 \pm 12.54$  mg/L for the filtered water,  $201.26 \pm 14.33$  mg/L for the treated water and  $202.03 \pm 8.62$  mg/L for the distributed water. There was no significant difference in TDS between the different sampling points ( $p > 0.05$ ) and were all within acceptable levels (1,000 mg/L) for drinking (WHO 2004a, b). The values did not exceed the critical value (1,000 mg/L) above which some long-term health problems might be anticipated (Kempster et al. 1997). According to MacCutcheon et al. (1983), the palatability of water with TDS level less than 600 mg/L is generally considered to be

good, whereas water with TDS greater than 1,200 mg/L becomes increasingly unpalatable. Hence, the water from the Water treatment plant could be considered palatable since the mean TDS for the samples in the distribution system were less than 600 mg/L. Barbooti et al. (2010) reported TDS levels of 486–864 mg/L which is higher than what is reported for this work.

Total suspended solids (TSS) are also indicators of pollution. Mean TSS values were  $7.60 \pm 3.23$  mg/L for the raw water. The settled water had a mean TSS value of  $6 \pm 2.40$  mg/L. Filtered water recorded  $1.40 \pm 0.93$ ,  $1.60 \pm 0.40$  mg/L for the chlorinated water and  $1.10 \pm 0.28$  mg/L for the distributed water. The difference in TSS from the raw water to the distributed water was significant ( $p < 0.05$ ). This means that the processes of flocculation, sedimentation, filtration and chlorination impacted significantly on the water samples. There was a slight increase in TSS during the chlorination process and this is as a result of the hypochlorite added to the water samples as a disinfectant.

It is known that  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  along with their carbonates, sulphates and chlorides confer hardness to the water (Alexander 2008). The recommended limit for hardness is 300 mg/L and the maximum permissible limit for potable water is 600 mg/L (BIS 1991), but the World Health Organization (WHO 2004a)-recommended safe permissible limit for Total Hardness (TH) is 100–500 mg/L. Mean TH values obtained were  $81.20 \pm 2.06$  mg/L for the raw water,  $88.00 \pm 8.10$  mg/L for the settled water,  $86.40 \pm 4.83$  mg/L for the filtered water,  $86.40 \pm 2.48$  mg/L for the chlorinated water and  $90.00 \pm 3.27$  mg/L for the distributed water. There was no significant change in the mean values of TH in the water samples for the different sites ( $p > 0.05$ ) and the values recorded were within the WHO acceptable levels. Water hardness at concentrations below 60 mg/L is generally considered as soft; 60–120 mg/L, moderately hard; 120–180 mg/L, hard; and more than 180 mg/L, very hard (McGowan 2000). The results shown in Table 4 indicate that the water from the water treatment plant is moderately hard.

Alkalinity refers to the water's ability to neutralize acids. Highly alkaline water is usually unpalatable. Mean alkalinity values are  $138.60 \pm 4.26$  for the raw water,  $121.80 \pm 5.39$  mg/L for the settled water,  $106.80 \pm 6.56$  mg/L for the filtered water,  $105.60 \pm 6.97$  mg/L for the chlorinated water and  $103.40 \pm 5.52$  mg/L for the distributed water. There is a significant change in alkalinity from the raw water to the filtered water and chlorinated water as well as distributed water ( $p < 0.05$ ) and were all at acceptable levels. The treatment processes impacted significantly on alkalinity. The aluminium sulphate, an acid salt, added at the sedimentation stage reacts with the alkalinity present in the water and reduces the alkalinity.

The water analysed is less alkaline than the water from Kohdasht City in Iran reported by Jafari et al. (2008) as 203.75–400 mg/L.

The mean, standard error of the mean and range of ions measured in the water samples at the different treatment points are presented in Table 2.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are among the most common ions present in natural waters and they contribute to water hardness. Calcium had mean levels of  $29.70 \pm 0.81$  mg/L for the raw water,  $30.02 \pm 1.30$  mg/L for the settled water,  $31.68 \pm 1.37$  mg/L for the filtered water,  $26.12 \pm 0.81$  mg/L for the chlorinated water and  $30.09 \pm 1.31$  mg/L for the distributed water. Magnesium, on the other hand, had mean concentrations of  $1.96 \pm 0.45$  mg/L for the raw water,  $4.77 \pm 1.33$  mg/L for the settled water,  $3.74 \pm 0.79$  mg/L for the filtered water,  $5.88 \pm 0.96$  mg/L for chlorinated water and  $5.54 \pm 1.27$  mg/L. There was no significant change in the concentrations of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ( $p > 0.05$ ) during the purification process, which indicates that the processes of water purification employed at the water treatment plant had no significant impact on  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  content. The filter beds were designed such that they do not remove  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  from the water samples because they are important ions needed for normal functioning of the human body. The  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  concentrations for this work are also lower than those observed in the water from Kohdasht city in Iran reported by Jafari et al. (2008).

There was no significant difference in the chloride content of all the samples ( $p > 0.05$ ). This shows the treatment processes had no significant impact on the chloride content of the water samples. The chloride content changed from  $28.20 \pm 1.46$  mg/L for the raw water,  $27.80 \pm 2.29$  mg/L for the settled water,  $26.20 \pm 2.18$  mg/L for the filtered water,  $26.20 \pm 2.27$  mg/L for the chlorinated water to  $27.50 \pm 1.68$  mg/L for the distributed water. The chloride content in the water samples was lower than the acceptable level (250 mg/L). High content of chloride gives a salty taste to the water. The limits of chloride have set down primarily from taste considerations (BIS 1991; WHO 1996). No adverse health effects on humans have been reported from intake of water containing high concentrations of chloride (Alexander 2008). The levels are higher than those reported by Adelekan and Ogunde (2012).

The mean levels of fluoride were  $1.23 \pm 0.20$  mg/L for the raw water,  $1.10 \pm 0.11$  mg/L for settled water,  $1.11 \pm 0.10$  mg/L for filtered water,  $1.28 \pm 0.18$  mg/L for chlorinated water and  $1.28 \pm 0.16$  mg/L for the distributed water. There was no significant change in the mean fluoride levels ( $p > 0.05$ ). The mean levels of fluoride in the water samples were not impacted significantly by the treatment processes. Large amounts of fluoride (above 1.5 mg/L) are associated with dental and skeletal fluorosis whereas low

**Table 2** The mean, standard error of the mean and the range of the ions in the water samples from the Owabi headworks ( $n = 5$ )

Parameter	RSV	MDT	MDT 1	AFT	DST	WHO limits (WHO 2004a, b)
<b>Ca</b>						
Mean $\pm$ SE	29.70 $\pm$ 0.81	30.02 $\pm$ 1.30	31.68 $\pm$ 1.37	26.12 $\pm$ 0.81	30.09 $\pm$ 1.31	200
Range	28.0–32.0	27.02–33.6	28.0–35.2	24.0–28.0	23.2–34.0	
<b>Mg</b>						
Mean $\pm$ SE	1.96 $\pm$ 0.45	4.77 $\pm$ 1.33	3.74 $\pm$ 0.79	5.88 $\pm$ 0.96	5.54 $\pm$ 1.27	150
Range	0.49–2.90	1.46–8.75	1.50–6.32	2.40–7.78	1.50–13.60	
<b>Cl<sup>-</sup></b>						
Mean $\pm$ SE	28.20 $\pm$ 1.46	27.80 $\pm$ 2.29	26.20 $\pm$ 2.18	26.20 $\pm$ 2.27	27.50 $\pm$ 1.68	250
Range	25–33	22–36	18–31	18–32	16–33	
<b>F<sup>-</sup></b>						
Mean $\pm$ SE	1.23 $\pm$ 0.20	1.10 $\pm$ 0.11	1.11 $\pm$ 0.10	1.28 $\pm$ 0.18	1.28 $\pm$ 0.16	1.5
Range	0.45–1.52	0.65–1.25	0.70–1.23	0.55–1.55	0.30–1.62	
<b>PO<sub>4</sub><sup>3-</sup></b>						
Mean $\pm$ SE	9.21 $\pm$ 4.83	11.36 $\pm$ 5.05	10.34 $\pm$ 5.07	9.86 $\pm$ 5.35	12.88 $\pm$ 4.55	400
Range	0.26–27.0	0.20–27.00	0.18–28.00	0.28–30.00	0.34–39.00	
<b>SO<sub>4</sub><sup>2-</sup></b>						
Mean $\pm$ SE	8.00 $\pm$ 1.00 <sup>a</sup>	46.80 $\pm$ 10.69 <sup>b</sup>	36.80 $\pm$ 7.38	32.00 $\pm$ 4.98	33.50 $\pm$ 5.65	400
Range	5–11	16–75	12–57	13–39	10–67	
<b>NO<sub>3</sub><sup>-</sup></b>						
Mean $\pm$ SE	0.49 $\pm$ 0.13	0.42 $\pm$ 0.11	0.86 $\pm$ 0.22	1.18 $\pm$ 0.42	1.54 $\pm$ 0.36	50
Range	0.10–0.88	0.10–0.68	0.08–1.35	0.08–2.33	0.09–3.30	
<b>NO<sub>2</sub><sup>-</sup></b>						
Mean $\pm$ SE	0.03 $\pm$ 0.01	0.02 $\pm$ 0.01	0.02 $\pm$ 0.01	0.03 $\pm$ 0.01	0.07 $\pm$ 0.02	3.0
Range	0.004–0.08	0.004–0.08	0.01–0.06	0.005–0.06	0.016–0.20	
<b>NH<sub>3</sub></b>						
Mean $\pm$ SE	0.01 $\pm$ 0.004	0.01 $\pm$ 0.004	0.02 $\pm$ 0.01	0.02 $\pm$ 0.01	0.01 $\pm$ 0.003	1.5
Range	0.00–0.02	0.00–0.02	0.00–0.05	0.00–0.04	0.00–0.03	
<b>R. Cl</b>						
Mean $\pm$ SE				1.14 $\pm$ 0.42	0.89 $\pm$ 0.30	–
Range				0.09–2.00	0.01–2.00	

levels below 0.6 mg/L may cause dental caries (BIS 1991). The levels are higher than 0.60–0.80 mg/L reported by Jafari et al. (2008).

The distributed water recorded the highest mean PO<sub>4</sub><sup>3-</sup> level of 12.88  $\pm$  4.55 mg/L followed by the settled water with a mean level of 11.32  $\pm$  5.05 mg/L. The filtered water had the next highest mean level of 10.34  $\pm$  5.07 mg/L followed by the chlorinated water with a mean level of 9.86  $\pm$  5.35 mg/L and then the raw water with a mean level of 9.21  $\pm$  4.83 mg/L. The differences in the phosphate levels were not significant ( $p > 0.05$ ) indicating that the purification process did not impact significantly on the PO<sub>4</sub><sup>3-</sup> levels in the water samples. Small amount of PO<sub>4</sub><sup>3-</sup> is added to the water which accounts for the levels of phosphate in the distribution system. The PO<sub>4</sub><sup>3-</sup> inhibits corrosion in the water mains and sequesters nuisance metals (Mn, Fe) in the water supply. Phosphates can also

improve the quality of water in the distribution system by removing scale deposits, discourage microbial film regrowth and stabilizing free chlorine disinfectant residuals. The PO<sub>4</sub><sup>3-</sup> levels are higher than that reported by Jafari et al. (2008) which is 0.11–0.31 mg/L.

SO<sub>4</sub><sup>2-</sup> had mean levels of 8.00  $\pm$  1.00 mg/L in the raw water, 46.80  $\pm$  10.69 mg/L in the settled water, 36.80  $\pm$  7.39 mg/L in filtered water, 32.00  $\pm$  4.98 mg/L in chlorinated water and 33.50  $\pm$  5.65 mg/L in the distributed water. There was a significant change in SO<sub>4</sub><sup>2-</sup> concentration from the raw water to the settled water ( $p < 0.05$ ). This increase is attributed to the aluminium sulphate added to the water to effect flocculation. Water containing magnesium sulphate at levels above 600 mg/L acts as a purgative in humans. The SO<sub>4</sub><sup>2-</sup> levels are higher than the levels in the selected streams from Brong Ahafo reported in Akoto and Adiyiah (2007) to be 3.33–8.02 mg/L.

**Table 3** The mean, standard error of the mean and the range of the metals in the water samples from the Owabi headworks ( $n = 5$ )

Parameter	RSV	MDT	MDT 1	AFT	DST	WHO limits (WHO 2004a, b)
<b>Mn</b>						
Mean $\pm$ SE	0.005 $\pm$ 0.001	0.015 $\pm$ 0.005	0.018 $\pm$ 0.006	0.015 $\pm$ 0.005	0.01 $\pm$ 0.002	0.1
Range	0.002–0.008	0.004–0.035	0.003–0.035	0.002–0.030	0.004–0.02	
<b>Cr</b>						
Mean $\pm$ SE	0.06 $\pm$ 0.005	0.06 $\pm$ 0.007	0.05 $\pm$ 0.01	0.04 $\pm$ 0.01	0.04 $\pm$ 0.003	0.05
Range	0.04–0.070	0.04–0.080	0.01–0.07	0.01–0.07	0.03–0.06	
<b>Cu</b>						
Mean $\pm$ SE	0.237 $\pm$ 0.146	0.118 $\pm$ 0.084	0.02 $\pm$ 0.008	0.016 $\pm$ 0.012	0.04 $\pm$ 0.02	0.1
Range	0.02–0.800	0.01–0.440	0.01–0.04	0.01–0.06	0.01–0.20	
<b>Zn</b>						
Mean $\pm$ SE	0.014 $\pm$ 0.005	0.034 $\pm$ 0.013	0.018 $\pm$ 0.006	0.012 $\pm$ 0.004	0.041 $\pm$ 0.018	3.0
Range	0.01–0.030	0.01–0.080	0.01–0.04	0.01–0.02	0.01–0.20	
<b>Fe</b>						
Mean $\pm$ SE	0.10 $\pm$ 0.032	0.10 $\pm$ 0.032	0.012 $\pm$ 0.008	0.014 $\pm$ 0.014	0.013 $\pm$ 0.009	0.3
Range	0.01–0.200	0.01–0.430	0.01–0.04	0.01–0.07	0.01–0.07	
<b>K</b>						
Mean $\pm$ SE	15.54 $\pm$ 1.713	16.52 $\pm$ 2.124	13.30 $\pm$ 1.338	10.84 $\pm$ 0.952	15.35 $\pm$ 1.826	30
Range	9.6–20.100	10.0–22.600	10.0–17.0	9.0–14.0	8.0–24.0	
<b>Al</b>						
Mean $\pm$ SE	0.096 $\pm$ 0.009	0.262 $\pm$ 0.031	0.106 $\pm$ 0.056	0.12 $\pm$ 0.015	0.11 $\pm$ 0.008	0.2
Range	0.07–0.120	0.15–0.330	0.01–0.31	0.09–0.16	0.07–0.15	

All parameters are in mg/L unless stated otherwise

SE Standard error of the mean

$\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$  are considered to be non-cumulative toxins (Dallas and Day 1993). High concentrations of  $\text{NO}_3\text{-N}$  and  $\text{NO}_2\text{-N}$  may give rise to potential health risks, particularly in pregnant women and infants under 6 years of age (Kempster et al. 1997). All the samples recorded  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$  concentrations lower than the WHO permissible limit for drinking water. The results are presented in Table 2. Change in nitrate and nitrite concentration followed a similar pattern;  $\text{RSV} > \text{MDT} < \text{MDT 1} < \text{AFT} < \text{DST}$  but that of ammonia had a different pattern;  $\text{RSV} < \text{MDT} < \text{MDT 1} > \text{AFT} > \text{DST}$ . The concentrations of each of  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$  were less than 2 mg/L at the different sampling points and, therefore, are not expected to exert any taste, odour or health problems.

Concentrations of  $\text{SO}_4^{2-}$ ,  $\text{PO}_4^{3-}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NH}_4\text{-N}$  in the samples were, generally, low which could probably be as a result of low runoffs since this work was done in the dry season. Ansa-Asare and Asante (1998) reported that there is a general decrease in the nutrient concentration in the dry season. Of all the nutrients, sulphate had very high concentration followed by phosphate in all the samples. Nutrient concentrations were of the following order:  $\text{NH}_3 < \text{NO}_2^- < \text{NO}_3^- < \text{PO}_4^{3-} <$

$\text{SO}_4^{2-}$ . The high phosphate can stimulate a rapid growth of photosynthetic algae and cyanobacteria resulting in eutrophication (Nthumbi et al. 2012) in the Owabi reservoir. Eutrophication could increase water treatment cost through filter clogging in treatment works. The high phosphate level in the reservoir may be attributed to phosphate-rich sewage material from the villages in the catchment which are dumped into the river (Akoto et al. 2010). It could also come from drains rich in detergents (Akpabli and Drah 2001).

The concentration of the metals and the standard error of the mean of the measurements are presented in Table 3. Metals have been referred to as common pollutants, which are widely distributed in the environment with sources mainly from the weathering of minerals and soils (O'Neil 1993). However, the level of these metals in the environment has increased tremendously in the past decades as a result of inputs from human activities (Marian 1991).

The mean concentrations of manganese in the water samples were  $0.005 \pm 0.001$  mg/L for the raw water,  $0.015 \pm 0.005$  mg/L for the settled water,  $0.018 \pm 0.006$  mg/L for the filtered water,  $0.015 \pm 0.005$  mg/L for chlorinated water and  $0.01 \pm 0.002$  mg/L for water samples in the distribution system. There was no significant



change in Mn concentrations at the different sampling sites and the concentration was within the WHO permissible level of 0.1 mg/L and poses no health concern. Mn is an essential metal. However, at excessive levels in the brain it produces extra pyramidal symptoms similar to those in patients with Parkinson's disease, and decreased learning ability in children as well as increased propensity for violence in adults (Finley 2004).

Chromium had a mean concentration of  $0.06 \pm 0.005$ ,  $0.062 \pm 0.007$ ,  $0.046 \pm 0.01$ ,  $0.016 \pm 0.012$  and  $0.044 \pm 0.022$  mg/L for the raw, settled, filtered, chlorinated and distributed water, respectively. The raw water had a mean concentration of  $0.06 \pm 0.005$  mg/L which was above the WHO limit of 0.05 mg/L but subsequent treatment reduced the concentration to acceptable levels. This can be explained by the fact that chlorine used in disinfection precipitated some of the Mn and Cr out.

Cu is an essential mineral to human health. Too much copper ( $>0.1$  mg/L), however, can cause health problems. Cu recorded a mean level of  $0.24 \pm 0.15$  mg/L for the raw water,  $0.12 \pm 0.084$  mg/L for the settled water,  $0.02 \pm 0.008$  mg/L for the filtered water,  $0.016 \pm 0.01$  mg/L for the chlorinated water and  $0.04 \pm 0.02$  mg/L for water in the distribution system. Dissolved copper salts are poisonous to some biota. The raw water had mean concentration that is above the WHO acceptable level of 0.1 mg/L but sedimentation and filtration processes reduced the concentration of Cu to acceptable levels.

Although Zn has been found to have low toxicity to man, prolonged consumption of large doses can result in some health complications such as fatigue, dizziness and neutropenia (Hess and Schmidt 2002). The Zn concentrations of all the samples analysed were all below the WHO acceptable limit of 3.0 mg/L. The recorded mean levels are  $0.014 \pm 0.005$ ,  $0.034 \pm 0.013$ ,  $0.018 \pm 0.006$ ,  $0.012 \pm 0.004$  and  $0.041 \pm 0.018$  mg/L for the raw, settled, filtered, chlorinated and distributed water, respectively.

Iron is not hazardous to health, but it is considered a secondary or aesthetic contaminant. Essential for good health, Fe helps transport oxygen in the blood. Fe recorded mean concentration of  $0.10 \pm 0.03$  mg/L for the raw water,  $0.10 \pm 0.03$  mg/L for the settled water, the filtered water  $0.01 \pm 0.008$  mg/L,  $0.014 \pm 0.014$  mg/L for the chlorinated water and  $0.013 \pm 0.009$  mg/L for the distributed.

Levels of potassium measured are  $15.54 \pm 1.71$  mg/L for the raw water,  $16.52 \pm 2.12$  mg/L for the settled water,  $13.30 \pm 1.34$  mg/L for filtered water,  $10.84 \pm 0.95$  mg/L for chlorinated water and  $15.35 \pm 1.83$  mg/L for the distributed water. Potassium has no health implications and is an essential element in plant, animal and human nutrition (Lewis 1997). In humans,  $K^+$  plays a critical role in many vital cell functions, such as metabolism, growth, repair and

**Table 4** The mean, standard error of the mean, and the range of the microbial quality of the water at the different treatment points of the Owabi water heads

Parameter	Total coliform (MPN/100 mL)	Faecal coliform (MPN/100 mL)
Sample		
RSV		
Mean $\pm$ SE	1,766.00 $\pm$ 401.55 <sup>a</sup>	257.00 $\pm$ 69.69 <sup>a</sup>
Range	240–2,400	93–430
MDT		
Mean $\pm$ SE	542.00 $\pm$ 440.75 <sup>b</sup>	38.20 $\pm$ 14.64 <sup>b</sup>
Range	49–2,300	5–90
MDT 1		
Mean $\pm$ SE	42.40 $\pm$ 10.03 <sup>c</sup>	0.00 <sup>c</sup>
Range	12–75	
AFT		
Mean $\pm$ SE	1.00 $\pm$ 1.00 <sup>c</sup>	0.00 <sup>c</sup>
Range	0–5	
DST		
Mean $\pm$ SE	18.20 $\pm$ 6.26 <sup>c</sup>	2.30 $\pm$ 2.30 <sup>c</sup>
Range	0–51	0–23
WHO recommended limit. (WHO 2004a, b)	0	0

SE standard error of the mean

<sup>a,b,c</sup> Denote different means

volume regulation, as well as in the electric properties of the cell. There were no significant changes in the concentrations of all the metals at the different sampling sites ( $p > 0.05$ ), which indicates that the processes of flocculation, sedimentation, filtration and chlorination had no significant impact on the metal concentrations in the samples.

Al recorded mean levels of  $0.096 \pm 0.009$  mg/L for the raw water,  $0.26 \pm 0.03$  mg/L for the settled water,  $0.11 \pm 0.06$  mg/L for the filtered water,  $0.12 \pm 0.01$  mg/L for the chlorinated water and  $0.11 \pm 0.008$  mg/L for the distributed water. The mean difference is significant at the 0.05 level. The settled water had an elevated level of  $Al^{3+}$  and it can be attributed to the aluminium sulphate added at this stage of treatment for flocculation and sedimentation.

The metals concentrations compares well with levels of metals found in the Densu river reported by Akpabli and Drah (2001) and selected streams from the Brong Ahafo region by Akoto and Adiyiah (2007). Akoto et al. (2008) as well as Badu et al. (2013) in their work reported on similar concentrations of iron, zinc, manganese and copper in the main tributaries of the Owabi river.

The mean, standard error of the mean and range for microbial analysis are presented in Table 4. Total and faecal coliforms were present in the raw water, which means that water from the reservoir is not suitable for domestic use without treatment. The raw water had total coliform count

**Table 5** Correlation coefficients of Colour, Turbidity, TSS and Alkalinity

	Colour	Turbidity	TSS	Alkalinity
Colour	1			
Turbidity	0.730*	1		
TSS	0.922*	0.843*	1	
Alkalinity	0.564*	0.564*	0.468*	1

\* Correlation is significant at the 0.01 level (2-tailed)

**Table 6** Correlation coefficient of the metals analysed

	Mn	Cr	Cu	Zn	Fe	K	Al
Mn	1						
Cr	0.239	1					
Cu	-0.201	0.202	1				
Zn	0.089	0.209	-0.028	1			
Fe	-0.196	0.342	0.459*	0.177	1		
K	-0.267	0.154	-0.035	-0.174	-0.088	1	
Al	0.100	0.423*	0.104	0.076	0.145	0.249	1

\* Correlation is significant at the 0.05 level (2-tailed)

of  $1,766.00 \pm 401.55/100$  mL and faecal coliform count of  $257.00 \pm 69.69/100$  mL. Akoto et al. (2010) observed that the high faecal coliform count in the streams that feed the Owabi watershed are signs of biological contamination of the streams by pathogens. The high faecal coliform levels observed make the reservoir unsuitable for swimming, boating and fishing (Millipore 1991; WHO 2004a). The results suggest that the general sanitary qualities of the water in the reservoir, as indicated by the total and faecal coliform counts, are unacceptable. For water to be considered as no risk to human health, the total and faecal coliform count/100 ml should be zero (WHO 2004a).

The poor microbiological quality might be due to contamination caused by human activities and livestock. It is a common practice for people living within the river catchment to discharge their domestic and agricultural wastes into rivers serving the reservoir (Karikari and Ansa-Asare 2006). However, there was significant reduction in coliform counts as the water underwent sedimentation, filtration and chlorination. The water records zero coliform count after chlorination which is in conformity with the accepted level (WHO 2004a).

Colour showed strong linear correlation ( $p < 0.01$ ) with turbidity ( $r = 0.730$ ), TSS (0.922) and alkalinity (0.564) as shown in Table 5.  $\text{NH}_3$  correlated linearly ( $r = 0.389$ ) with  $\text{PO}_4^{3-}$ .  $\text{Mg}^{2+}$  correlated linearly with F ( $r = 0.409$ ) and Cr also correlated linearly with  $\text{Al}^{3+}$  ( $r = 0.423$ ) significant at the 0.05 level.  $\text{Ca}^{2+}$  had negative correlation with  $\text{Mg}^{2+}$  ( $r = -0.447$ ) at 0.05 level (Table 6).

## Conclusion

The study found out that some physico-chemical properties like pH, temperature, hardness, TDS and TSS of the raw water were within the WHO acceptable limits and pose no risk to consumers even if the water had been used without prior treatment. However, parameters like colour, turbidity total and faecal coliform were above the WHO acceptable limit before treatment but were reduced to acceptable levels after passing through the treatment process thus making the water wholesome for drinking and domestic use.

Concentrations of all the nutrients ( $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{PO}_4^{3-}$  and  $\text{NH}_3$ ) were within acceptable levels in all the samples. Levels of phosphate and sulphate in the raw water were slightly higher, an indication of pollution in the raw water. Cr and Cu levels in the reservoir were above the WHO permissible limits. The levels of these two metals fell within acceptable limits after the water has been treated. The other metals (Mn, Zn, Fe, K and Al) recorded concentrations that were within acceptable levels at the different stages of treatment.

From the study it could be said that the microbiological quality of the raw water was poor indicating pollution of the Owabi reservoir. Subsequent treatment reduced the coliform level drastically and the water samples had no coliform count after chlorination. This indicates that each stage of the treatment process is important and essential part of the overall treatment of water. The results have also shown that the quality of the water distributed to consumers compares favourably with the water after chlorination and this indicates that the distribution system is working well. It can be concluded that the treatment processes at the Owabi water treatment plant is working very well as expected, delivering good quality water to the consumers.

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