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Physicochemical Quality and Trace Metal Levels of Municipal Water from Three Reservoirs in Osun State, Nigeria

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Abstract: The physicochemical quality of municipal water from three waterworks in Osun State, Nigeria was monitored in terms of temperature, pH, electrical conductivity, dissolved oxygen, solids (total, suspended and dissolved), nitrates and phosphates from April, 2003 to March, 2004 in order to assess the adequacy of treatment at the waterworks. The trace metal levels as well as the microbial quality of the municipal water from these waterworks were also monitored for the same length of time to establish their pollution levels.

The temperature values varied between 24.6^o C and 32.0^o C. The annual mean pH values for the three municipal water varied between 6.92 and 7.54 and therefore conforms with the WHO guideline of <8.0 in drinking water. The electrical conductivity values obtained ranged from 120.05 µS/cm to 265.00 µS/cm.

The mean levels of oxygen-demanding substances, nitrate, phosphate, total solids and dissolved solids were generally low and ranged from 6.23 mg/l to 8.99 mg/l; Not Detected (ND) to 2.59 mg/l; ND to 3.56 mg/l; 77.33 mg/l to 180.00 mg/l and 58.27 mg/l to 116.67 mg/l respectively. The concentrations of these substances were within safe limits. The coliform population varied from zero to 93 coliforms per 100 ml, the total bacteria count ranged between 0.3×10^4 Cfu/ml and 45.50×10^8 Cfu/ml while *Escherichia coli* was rarely detected throughout the study. Among the nine trace metals of interest only Hg, As and Cd occurred at concentrations above the WHO limits for drinking water and this give cause for concern.

Key words: Municipal water, trace metals, reservoirs, physico-chemical, contamination.

Introduction

Water contaminated with microbiological and chemical constituents can cause a variety of diseases. Water intended for human consumption should be safe, palatable and aesthetically pleasing; however, no source of water intended for human consumption can be assumed to be free from pollution. In developing countries such as Nigeria, the availability of safe and clean water for drinking and other domestic purposes is a serious problem. Municipal water supplies also could not be trusted, since results of analysis of drinking water supplies in three states in Southeastern Nigeria showed levels of mercury above the WHO allowable limits (Nkono and Asubiojo, 1998).

Measurement of dissolved oxygen indicates the degree of pollution by organic matter, the destruction of organic substances and the level of purification of water (Chapman 1996). Measurements of dissolved oxygen therefore provide a good indication of water quality (Wilcock et al., 1981; DFID, 1999). Electrical conductivity measures the ability of water to conduct electric current. It is a rough indicator of mineral content of the water. The suspended solids in the water are also of importance because of influence on turbidity and transparency of the water.

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Poor microbiological quality of water may result in diseases like campylobacteriosis, shigellosis, cholera and a variety of other bacterial as well as fungal, viral and parasitic infections (Grabow, 1996). Drinking of water polluted by faecal contamination may induce the multiplication of intestinal pathogens, and consequently complicate health problems (Verma and Srivastava, 1990; Ogunfowokan et al., 2000; Ogunfowokan et al., 2008). It therefore becomes imperative to critically monitor the microbial quality of municipal waters so that remedial actions can be taken where necessary and a decline in infectious and other communicable diseases will be recorded and ultimately improve the health standards of the citizens. The organisms most commonly used as indicators of faecal pollution are the coliform group and *Escherichia coli* in particular. Some water used for drinking and for other domestic purposes have been found to contain faecal coliforms, which are higher than guideline values (Fatoki et al., 2001; Nevondo and Cloete, 1999).

The pH of a water body affects the availability and toxicity of many pollutants (Hammer, 1975). Lowered pH could decrease the solubility of elements like selenium while the solubility of Al, As, Mn, Cu and Zn is increased thus increasing their deleterious effects (Morrison et al., 2001). Interest in metals like Fe, Mn, Zn and Cu, which are required for metabolic activities in organisms, lies in the "narrow window" between their essentiality and toxicity (DWAF, 1996b). Others like Pb, Cd and Hg exhibit extreme toxicity even at trace levels and they have bioaccumulation effects, thus necessitating their regular monitoring. The concentration of Cd in unpolluted water is usually less than 0.001 mg/l. Chronic effects of Cd include kidney damage and pain in the bones (itai itai disease) (Spear, 1981; Ogunfowokan et al.). In man, the chronic effects of lead include neurological disorders especially in foetus and children, behavioural changes and impaired performance in Intelligent Quotient (IQ) tests (Kjellstroem, 1980; Ogunfowokan et al., 2000).

The pollution of our environment – soil, water and air – causes one form of illness or the other and the concentrations of these environmental pollutants causing or aggravating illnesses may just need to be at trace levels. Therefore adequate characterization of municipal water samples is needed in order to have reliable pollution monitoring and predict whether or not there is an indication of a potential health risk. This study is concerned with the physicochemical and bacteriological quality assessment of the municipal waters from three water works in Osun State Nigeria viz., Obafemi Awolowo University campus and Asejire and Ede waterworks for a period of one year. The investigated water quality parameters include pH, temperature, electrical conductivity, nitrate, phosphate, total solids, dissolved solids, oxygen demanding substances and trace metals. The results are discussed and compared with those of international set standards for drinking water.

Materials and Methods

Pretreatment

Polyethylene bottles used for sampling for the determination of physicochemical parameters of samples and all glassware were washed thoroughly with detergent while sample containers for phosphate determination were washed with soap that does not contain phosphate. These were rinsed with tap water and then distilled water. The containers were subsequently soaked in 10% HNO_3 acid (v/v) for 48 hours prior to use.

Sampling

Municipal water were collected monthly from each of the three reservoirs in Osun State, Nigeria – viz., Asejire, Ede and Opa reservoirs, located at Asejire, Ede and Obafemi Awolowo University (OAU) campus, Ile-Ife respectively for a period of twelve months, April, 2003 to March 2004.

Temperature, pH and Electrical Conductivity

The temperatures of samples were taken in situ using mercury-in-glass thermometer with 0.1°C graduations. The pH was measured immediately after sample collection using a digital pH meter model H18519 (Hanna Instrument). Calibration of the electrode with buffer solutions of pH 4 and 9 was done prior to pH measurements. Electrical conductivity was measured using a Metler Toledo MC 126 Conductivity meter, which was calibrated with Conductivity Standard 1413 μScm^{-1} at 25°C.

Dissolved Oxygen (DO), Solids and Nutrients

The Winkler method was used in calculating the DO by adopting the method described by Bartram and Balance, 1996. The DO of the samples was fixed by appropriate volumes of manganous sulphate solution and alkaline-iodide-azide solution. The brown floc formed was allowed to settle to about two-thirds of the way down the bottle, after which 1.0 cm^3 concentrated H_2SO_4 was added. The bottles were restoppered and the contents inverted several times until the floc disappeared. It was then titrated with 0.025 mol/dm^3 sodium thiosulphate until a pale yellow colour resulted. Then 1.0 cm^3 of starch solution was added and titration continued until an endpoint (colourless) was achieved. The dissolved solid (DS) was measured using a Metler Toledo MC 126 model conductivity meter while the total solid (TS) was determined by gravimetric method and the total suspended solid was enumerated by difference.

For the nitrate determination, 0.5 ml of 1 moldm^{-3} HCl was added to 25 ml of sample, a blank was prepared to zero the α-Heλios Pye-Unicam double beam UV spectrophotometer at 220 nm and 270 nm. This is because certain organic compounds are absorbed at 220 nm. The absorbances of standard nitrate solutions were taken at these wavelengths and the values were used to plot a calibration curve. The corresponding nitrate concentrations of samples were extrapolated from the curve (Bartrman and Balance, 1996). The phosphate concentration was determined using Vanado-molybdo-phosphoric acid colorimetric method (Manav, 2002). This method is based on the reaction of ammonium molybdate under acidic conditions to form a molybdo-phosphoric acid in dilute orthophosphate solution. In the presence of vanadium used as soluble ammonium trioxo-vanadate(v), a yellow coloured complex is formed. The intensity of the yellow colour is proportional to the phosphate concentration in the solution. A α-Heλios Pye-Unicam double beam UV Spectrophotometer was used to measure the colour intensity at 470 nm.

Coliform and Bacteria Count

The plating for total bacteria count was done by the pour-plate method. 1.0 cm^3 of the water sample was pipetted from thick-walled amber bottles into 9.0 cm^3 sterilized water to give an initial 1:10 dilution (10^{-1}). This initial dilution was shaken and 1.0 cm^3 portion was transferred to the second dilution tube to give 1:100 dilution. This process was continued till the desired dilution that gives a count between 30 and 300 was obtained. 1.0 cm^3 each of the last three dilutions was transferred into each pair of petri dishes after which 10 cm^3 of plate count agar was added. The petri dishes were tilted and rotated on the table so as to mix the content. The agar was then left to solidify. All the plates were inverted and incubated at 37°C for 24 hours to encourage the growth of bacteria. The number of colonies that fell within the acceptable range (30-300) per plate was counted. To obtain the actual total bacteria count in the sample, the number of colonies per plate was divided by the dilution factor. The total coliform population of samples was enumerated by the multiple tube fermentation also known as most probable number (MPN) technique (Bartrman and Balance, 1996).

Lactose broth in fermentation tubes was used as the presumptive test medium. For each sample, three tubes containing 10 cm^3 each of double strength Lactose broth and six tubes containing 10 cm^3 each of single strength Lactose broth were used. Each of the test tubes contained an inverted Durham tube to indicate gas production. To each of the 10cm^3 double strength broth, 10 cm^3 of sample was added. 1.0 cm^3 water sample was added to three of the 10 cm^3 single strength broth and 0.1 cm^3 sample was added to the last three tubes. The fermentation tubes were incubated at 37° C for 48 hours. Formation of gas and turbidity within the inverted Durham tubes constitutes a positive presumptive test. All fermentation tubes showed a quantity of gas at the end of the incubation period and were subjected to confirmed test. Eosin methylene blue agar plates were streaked from the selected positive tubes in such a way as to ensure the presence of discrete colonies. The plates were incubated at 37° C for 24 hours. The presence of green metallic sheen indicates the presence of *Escherichia coli*, a typical coliform (Bartrman and Balance, 1996; Ademoroti, 1996; Okoronkwo and Odeyemi, 1985).

Trace Metals

Preparation of samples for trace metal determination was carried out by using the standard APHA (1992). Worked-up samples were analysed for trace metals of interest using a Chemtech Analytical Alpha-4 Flame Atomic Absorption Spectrophotometer (UK) after acid digestion. For quality control, water samples were spiked with known amount of standard Pb, Cu, Cd, Mn, Fe, Zn, Ni and As using the method described by AOAC (1990).

Results and Discussion

The results of 12 months assessment of physicochemical quality and trace metal levels of municipal water from three reservoirs in Osun State Nigeria are presented in Tables 1-4 and Figures 1-3.

Results of the analysis presented in Tables 1-3 showed that temperature varied between 24.5°C and 32.0°C. Generally the highest temperatures were recorded in March for Asejire (32.0°C) and Ede (31.2°C) municipal water respectively while the highest temperature (30.0°C) was recorded for Opa municipal water in April. This result is in agreement with the equally high temperature of 32°C recorded by Peters and Odeyemi, (1985) for Mokuro dam, Ile Ife from the same region where this investigation was conducted. The mean levels of oxygen-demanding substances in the water samples as presented in Tables 1 to 3 showed that the overall means for dissolved oxygen

Table 1: Physicochemical quality of treated water from Asejire reservoir

Quality	*Apr, 2003*	*May, 2003*	*Jun, 2003*	*Jul, 2003*	*Aug, 2003*	*Sept, 2003*	*Oct, 2003*	*Nov, 2003*	*Dec, 2003*	*Jan, 2004*	*Feb, 2004*	*Mar, 2004*	*Annual Mean*
Temperature (°C)	28.50	26.00	25.00	24.50	24.50	25.50	28.70	28.70	28.50	27.40	29.40	32.00	27.39
pH	7.05	7.43	6.99	7.61	7.07	8.47	8.08	7.91	8.15	8.09	6.97	6.63	7.54
	+	+	+	+	+	+	+	+	+	+	+	+	
	0.06	0.22	0.03	0.01	0.04	0.07	0.14	0.01	0.02	0.07	0.04	0.01	
Electrical Conductivity	217.00	223.00	241.00	265.00	170.70	161.57	149.40	154.40	171.77	157.07	160.33	161.00	186.02
(µS/cm)	+	+	+	+	+	+	+	+	+	+	+	+	
	0.09	0.42	0.13	0.01	0.21	0.23	0.58	0.30	0.15	0.15	0.50	0.17	
Phosphate-P (mg/l)	ND	ND	ND	ND	ND	ND	0.46	0.38	ND	ND	0.32	0.43	0.13
							+	+			+	+	
							0.09	0.00			0.06	0.09	
Nitrate-N (mg/l)	0.13	0.39	1.70	3.52	2.52	0.03	0.04	0.03	0.04	0.07	ND	0.09	0.71
	+	+	+	+	+	+	+	+	+	+		+	
	0.01	0.01	0.07	0.02	0.06	0.001	0.00	0.001	0.01	0.002		0.01	
N : P	-	-	-	-	-	-	0.09	0.08	-	-	-	0.21	0.03
Total Solids (mg/l)	106.67	130.00	133.33	113.33	138.93	160.40	94.68	104.34	114.38	96.00	93.33	110.00	116.33
	+	+	+	+	+	+	+	+	+	+	+	+	
	11.55	10.00	11.55	11.55	0.35	0.10	0.26	10.32	16.73	16.73	23.09	11.55	
Dissolved Solids	100.00	116.67	97.83	99.05	85.60	80.40	74.75	76.77	85.00	78.38	79.57	80.60	87.89
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	20.00	5.77	0.21	0.22	0.35	0.10	0.26	0.12	0.10	0.13	0.32	0.11	
Suspended Solids	10.00	13.33	35.50	14.28	53.33	80.00	20.00	27.57	36.00	17.62	13.76	29.40	29.23
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	15.28	5.77	0.21	0.22	23.10	20.00	0.00	10.32	16.73	0.13	0.32	0.11	
Dissolved Oxygen	7.11	7.66	7.77	7.94	8.33	7.60	7.27	7.33	6.99	7.61	7.33	6.23	7.43
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	0.09	0.33	0.09	0.38	0.00	0.19	0.10	0.00	0.00	0.19	0.19	0.10	

Table 2: Physicochemical quality of treated water from Ede reservoir

Quality	*Apr, 2003*	*May, 2003*	*Jun, 2003*	*Jul, 2003*	*Aug, 2003*	*Sept, 2003*	*Oct, 2003*	*Nov, 2003*	*Dec, 2003*	*Jan, 2004*	*Feb, 2004*	*Mar, 2004*	*Annual Mean*
Temperature (°C)	30.00	28.00	27.50	27.00	26.90	26.20	26.90	25.90	26.50	25.50	27.80	31.20	27.45
pH	7.43	7.13	7.09	6.33	6.72	7.88	6.81	7.26	7.88	7.95	6.87	8.05	7.28
	+	+	+	+	+	+	+	+	+	+	+	+	
	0.01	0.01	0.00	0.02	0.04	012	0.04	0.01	0.04	0.11	0.02	0.01	
Electrical Conductivity	135.20	126.30	146.50	181.80	161.80	138.23	120.05	130.43	139.27	132.00	134.67	136.53	140.23
(µS/cm)	+	+	+	+	+	+	+	+	+	+	+	+	
	0.23	0.96	0.81	1.00	0.46	0.56	1.84	0.15	0.21	0.10	0.15	0.06	
Phosphate-P (mg/l)	1.95	0.39	ND	ND	ND	0.07	ND	0.44	ND	ND	0.39	0.49	0.31
	+	+				+		+			+	+	
	0.23	0.44				0.18		0.11			0.06	0.06	
Nitrate-N (mg/l)	0.54	0.87	1.17	2.55	2.55	0.03	0.04	0.02	0.04	0.15	ND	0.07	0.67
	+	+	+	+	+	+	+	+	+	+		+	
	0.04	0.15	0.01	0.01	0.06	0.00	0.00	0.00	0.001	0.07		0.004	
N : P	0.28	2.23	-	-	-	0.43	-	0.05	-	-	-	0.14	0.26
Total Solids (mg/l)	90.00	90.00	73.33	153.33	174.13	142.36	86.60	88.61	100.83	120.00	106.67	110.00	111.32
	+	+	+	+	+	+	+	+	+	+	+	+	
	10.00	10.00	11.55	11.55	0.00	0.15	0.75	20.00	19.15	0.15	11.55	11.55	
Dissolved Solids	70.00	73.33	58.27	72.63	80.80	69.03	60.03	65.37	69.73	65.83	67.20	69.00	68.44
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	10.00	11.55	0.25	0.12	0.00	0.15	0.64	0.12	0.06	0.12	0.00	0.10	
Suspended Solids	20.00	16.67	15.06	80.70	93.33	73.33	26.67	23.24	35.00	54.17	39.47	41.00	43.22
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	10.00	11.55	0.25	0.12	23.14	11.55	11.55	0.12	19.15	0.15	0.00	0.10	
Dissolved Oxygen	6.41	7.10	7.88	8.05	8.33	7.77	7.55	7.53	7.49	7.61	7.33	6.33	7.45
(mg/l)	+	+	+	+	+	+	+	+	+	+	+	+	
	0.33	0.26	0.39	0.09	0.00	0.35	0.19	0.22	0.19	0.09	0.19	0.29	

Table 3: Physicochemical quality of treated water from Obafemi Awolowo University reservoir

Quality	*Apr, 2003*	*May, 2003*	*Jun, 2003*	*Jul, 2003*	*Aug, 2003*	*Sept, 2003*	*Oct, 2003*	*Nov, 2003*	*Dec, 2003*	*Jan, 2004*	*Feb, 2004*	*Mar, 2004*	*Annual Mean*
Temperature (°C)	30.00	26.00	27.00	27.50	27.00	27.00	27.60	28.00	28.00	27.60	27.60	29.00	27.69 + 1.03
pH	6.70 + 0.00	6.94 + 0.10	7.54 + 0.03	7.09 + 0.00	7.02 + 0.02	5.81 + 0.05	7.26 + 0.46	6.70 + 0.03	6.36 + 0.02	7.46 + 0.39	7.94 + 0.02	6.20 + 0.03	6.92 + 0.61
Electrical Conductivity (µS/cm)	263.00 + 1.05	247.00 + 0.36	251.00 + 0.19	242.00 + 0.01	181.60 + 0.40	149.73 + 0.12	174.85 + 2.59	171.37 + 0.40	173.83 + 0.06	183.20 + 0.00	191.70 + 0.10	232.00 + 0.00	205.11 + 38.86
Phosphate-P (mg/l)	3.56 + 0.25	ND	ND	ND	ND	0.05 + 0.10	ND	0.38 + 0.00	ND	ND	0.42 + 0.16	0.35 + 0.10	0.39 + 1.01
Nitrate-N (mg/l)	0.48 + 0.00	0.57 + 0.31	0.84 + 0.01	2.59 + 0.03	1.18 + 0.05	0.02 + 0.00	0.02 + 0.001	0.02 + 0.003	0.03 + 0.00	0.12 + 0.003	ND	0.05 + 0.01	0.49 + 0.77
N : P	0.13	-	-	-	-	0.43	-	0.05	-	-	-	0.14 + 0.01	0.06 + 0.13
Total Solids (mg/l)	150.00 + 10.00	160.00 + 20.00	120.00 + 20.00	100.00 + 0.00	130.51 + 0.44	94.70 + 0.10	100.26 + 1.09	109.15 + 19.15	118.04 + 11.55	105.00 + 34.16	125.00 + 19.15	180.00 + 0.00	124.39 + 26.60
Dissolved Solids (mg/l)	116.67 + 15.23	130.00 + 10.00	99.00 + 0.00	97.27 + 0.31	90.83 + 0.15	74.70 + 0.10	86.93 + 1.09	85.13 + 0.12	86.73 + 0.06	91.37 + 0.15	95.87 + 0.06	115.67 + 0.58	97.51
Suspended Solids (mg/l)	33.33 + 15.28	30.00 + 10.00	21.00 + 0.00	2.73 + 0.31	40.00 + 0.00	20.00 + 0.00	13.33 + 11.55	24.02 + 19.15	26.67 + 11.55	13.63 + 0.15	29.13 + 0.06	64.33 + 0.58	26.51
Dissolved Oxygen (mg/l)	6.34 + 0.07	7.38 + 0.42	8.05 + 0.25	8.99 + 0.00	8.05 + 0.09	7.22 + 0.19	7.77 + 0.38	7.33 + 0.00	7.39 + 0.09	7.56 + 0.25	6.99 + 0.00	6.67 + 0.17	7.48

Table 4: Microbiological quality of municipal water samples from three reservoirs in Osun State, Nigeria

		Apr, 2003	*May, 2003*	*Jun, 2003*	*Jul, 2003*	*Aug, 2003*	*Sept, 2003*	*Oct, 2003*	*Nov, 2003*	*Dec, 2003*	*Jan, 2004*	*Feb, 2004*	*Mar, 2004*
Total Coliform per 100 ml	A_2	93	3	0	4	0	0	4	0	4	4	9	0
	B_2	4	4	15	4	0	3	3	0	0	7	0	0
	C_2	93	7	4	9	4	0	7	0	15	4	7	9
Total Bacteria Count (Cfu/ml)	A_2	22.25×10^8	24.25×10^8	0.16×10^8	1.40×10^8	0.50×10^5	5.10×10^4	0.15×10^4	3.50×10^5	11.00×10^4	0.50×10^5	2.50×10^5	2.00×10^4
	B_2	23.75×10^8	45.50×10^8	0.11×10^8	0.70×10^8	6.50×10^5	3.00×10^4	0.65×10^4	1.00×10^5	1.00×10^4	1.50×10^5	0.50×10^5	3.00×10^4
	C_2	18.75×10^8	45.25×10^8	0.13×10^8	1.57×10^8	1.17×10^5	1.60×10^4	0.30×10^4	2.00×10^5	2.00×10^4	1.25×10^5	3.45×10^5	4.00×10^4
Escherichia coli	A_2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	B_2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	C_2	E coli	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

A_2 = Municipal water from Asjire reservoir, B_2 = Municipal water from Ede reservoir, C_2 = Municipal water from OAU reservoir, ND = Not detected.

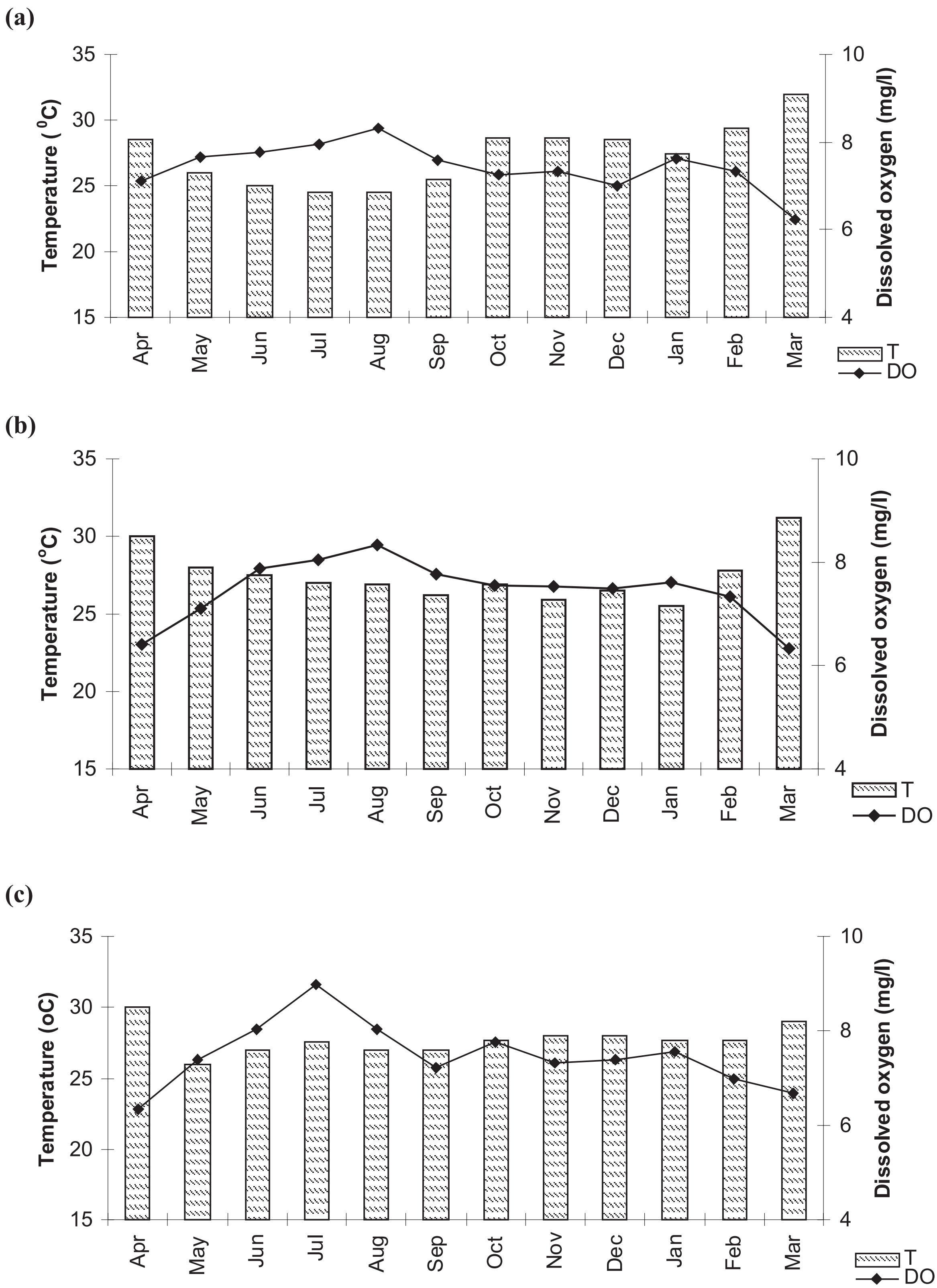

Figure 1: Temperature-Dissolved Oxygen relationship of treated water: a = Asejire, b = Ede and c = OAU reservoirs respectively.

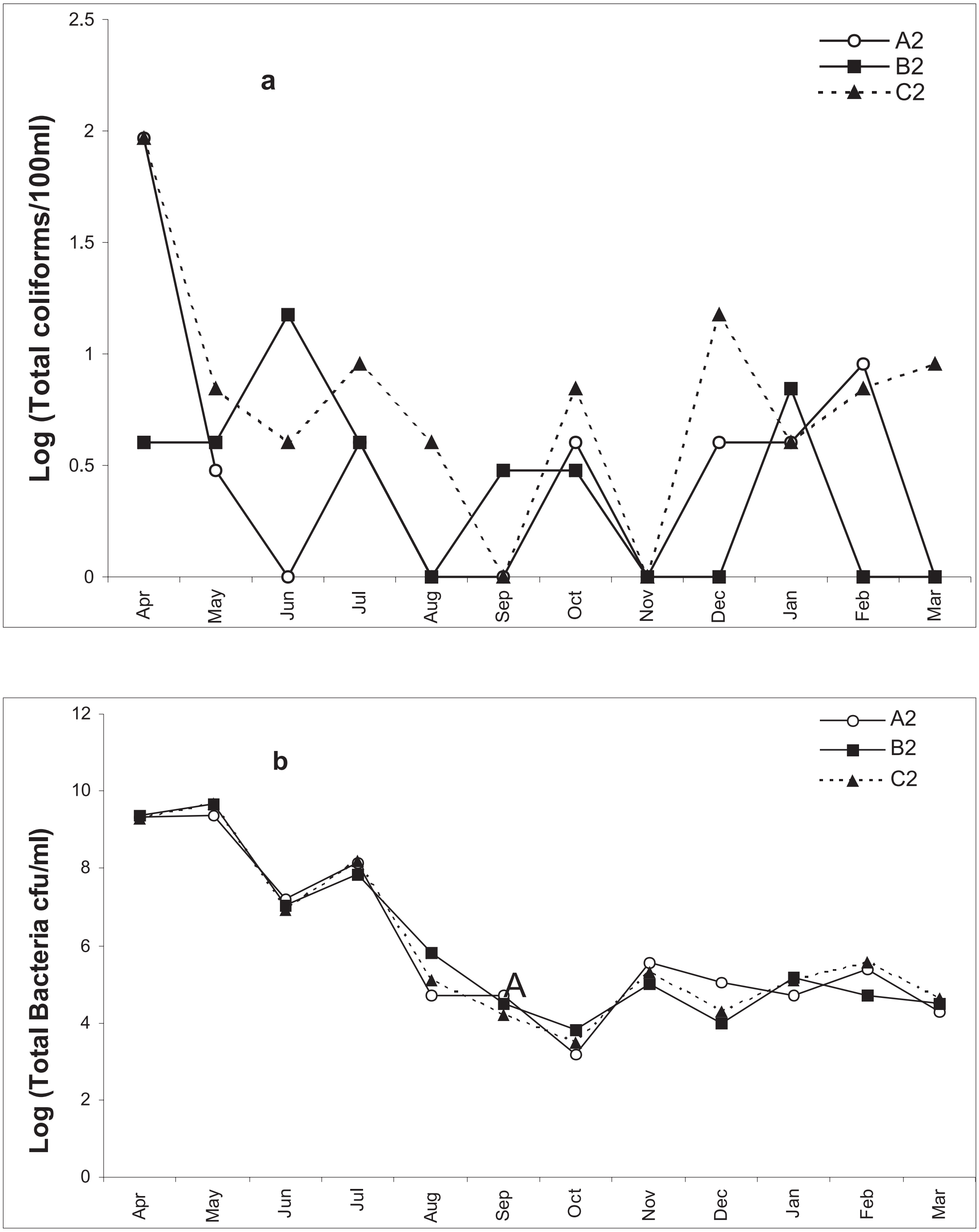

Figure 2: Microbiological quality of municipal water: A2, B2, C2 = Municipal water samples from Asejire, Ede and OAU reservoirs respectively.

varied between 7.43 mg/l and 7.48 mg/l in Asejire and Ede municipal waters respectively. The DO levels in unpolluted water are normally about 8 to 10 mg/l (at 25°C) (DFID, 1999) and concentrations below 5 mg/l can adversely affect aquatic life (DFID, 1999; Fatoki et al., 2003). The results of DO concentrations in the municipal water samples investigated are therefore within the limits for unpolluted water. DO is an important factor for water quality control and thus provides a broad indicator of water quality.

Figure 1 (a, b and c) illustrates variation in the DO with temperature. This study showed that DO is minimal in Asejire (a), Ede (b) and OAU (c) municipal waters when the sample temperatures were highest. For example,

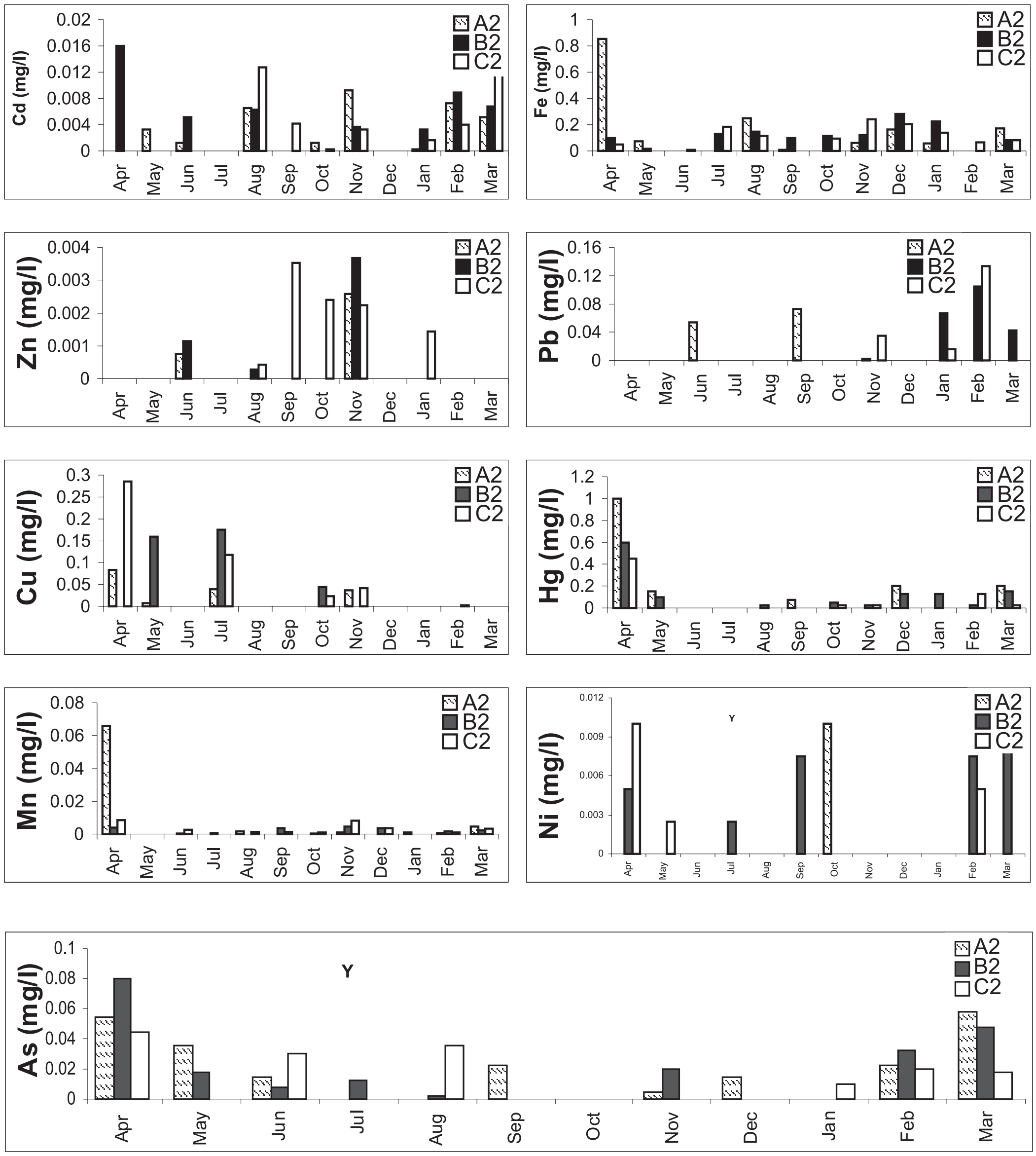

Figure 3: Trace metal levels in the water samples: A2, B2, C2 = Municipal water from Asejire, Ede and OAU reservoirs respectively.

at Asejire, the highest temperature was recorded in March (32.0°C), which corresponds to the lowest DO of 6.23 + 0.10 mg/l as shown in Figure 1(a). In Ede municipal water, Figure 1(b), the highest temperature (31.2°C) was obtained in March with the lowest DO of 6.33 + 0.29 mg/l while in OAU municipal water, Figure 1(c), the highest temperature of 30.0°C in April corresponds to the least DO of 6.34 + 0.07 mg/l. This observation is in agreement with the general scientific fact that increase in temperature leads to a decrease in dissolved gases. A similar observation of DO levels of 15 mg/l at 0°C and 8 mg/l at 25°C has been reported by Chapman (1996). It is worth mentioning, however, that the metabolic rate of aquatic organisms is also related to temperature such that in warm waters, respiration rates increase leading to increased oxygen consumption and increased decomposition of organic matter (Chapman, 1996).

pH and Electrical Conductivity (EC)

The annual mean pH values for the municipal water from the three reservoirs varied between 6.92 and 7.54 in OAU and Asejire respectively (Tables 1 to 3). The WHO pH guidelines for drinking water is <8.0 for effective disinfections with chlorine (WHO, 1993). EU sets protection limit of 6 to 9 pH range for fisheries and aquatic life (Chapman, 1996). Considering these guidelines, the annual mean pH values of all the samples show suitability for use as potable water. The electrical conductivity of most freshwaters ranges 10-1000 µS/cm but may exceed 1000 µS/cm especially in polluted waters or water receiving large quantities of land run-off (Koning and Ross, 1999). The South African acceptable limit for conductivity in domestic water supply is 70 mS/m (DWAF, 1996a). The results of EC in this study show that all the water samples analysed from municipal water from the three reservoirs were within the electrical conductivity range of unpolluted waters.

Solids

The annual mean total solids varied from 111.32 mg/l to 124.39 mg/l in Ede and OAU municipal waters respectively. Furthermore, the annual mean dissolved solids were between 68.44 mg/l and 97.51 mg/l in Ede and OAU municipal waters, whereas the suspended solids varied between 26.51 mg/l in OAU and 43.22 mg/l in Ede municipal waters. The standard limit for total solids in drinking water stipulated by the Nigerian Federal Environmental Protection Agency (FEPA, 1990) and the United States Environmental Protection Agency (USEPA, 1986) is 500 mg/l; this limit had not been exceeded in all the water samples. However, there is need to keep the solids in the drinking water low, so that the solids may not become a vehicle for bacteria penetration of treatment barriers, since turbid waters contain particles with embedded bacteria that can protect the effect of chlorination (Geldreich et al., 1982).

Nutrients

The annual means NO_3^--N in the municipal water samples from OAU, Ede and Asejire reservoirs were 0.49 mg/l, 0.67 mg/l and 0.71 mg/l respectively, while the annual means PO_4^{3-}-P were 0.13 mg/l, 0.31 mg/l and 0.39 mg/l for Asejire, Ede and OAU municipal waters respectively. The WHO safe limit for nitrate in domestic water for lifetime use is 10 mg/l (WHO, 1984). This nitrate level was not exceeded in all the municipal waters hence the water samples are suitable for direct domestic use and may not expose infant and pregnant women to the risk of methaemoglobinemia (Bush and Mayer, 1982).

Microbial Quality

The total coliform populations ranged from zero to 93 coliforms/100 ml in the municipal water samples from Asejire and OAU reservoirs and from zero to 15 coliforms/100 ml in water samples from Ede reservoir (Table 4). Figure 2(a) illustrates variations of coliform population in the municipal water samples. The annual mean total coliforms from Asejire, Ede and OAU reservoirs were 0.10×10^2 coliforms/100 ml, 0.03×10^2 coliforms/100 ml and 0.13×10^2 coliforms/100 ml respectively. All the water samples analysed contained total coliforms higher than the WHO guideline value of zero coliforms/100 ml. *Escherichia coli*, a typical coliform which indicates recent faecal contamination was not detected except for the month of April in OAU municipal water (Table 4).

The monthly total bacteria count of the municipal water from the reservoirs are also presented in Table 4. The annual means of 3.98×10^8 cfu/ml, 5.84×10^8 cfu/ml and 5.48×10^8 cfu/ml were obtained for Asejire, Ede and OAU waters respectively. These values were far above 0 cfu/ml and faecal 10 cfu/100 ml total coliforms South African maximum recommended guideline limits for no risk. Figure 2(b) further illustrates the bacteria count in the water samples showing the logarithm of total bacteria. The WHO (1984) drinking water guideline required that coliform bacteria must not be present in 95% of samples taken through any 12-month period; however, coliform bacteria was detected in all the water samples all the time. The high total bacteria and total coliform detected in this study revealed that the microbiological quality of the municipal water samples analysed was poor, unsafe and not acceptable for human consumption. This indicates the potential risk of infection for consumers and therefore calls for prompt intervention to mitigate the socio-economic and health impacts of water-borne diseases.

Trace Metals

The results of quality control study for the water samples were obtained as percentage recoveries of the trace metals from spiked water samples using standard addition method. The percentage recoveries of these elements – Pb, Cu, Cd, Mn, Fe, Zn, Ni and As – ranged from 63.60% to 106.00%. The high percentage recoveries obtained indicate that the sample preparation method and the analytical procedure described in this study were satisfactory.

The annual mean cadmium concentration in Asejire municipal water was 0.0029 mg/l whereas for Ede and OAU, the annual mean cadmium concentrations were 0.0067 mg/l and 0.0033 mg/l respectively. The levels of cadmium in the water samples show no specific trend as indicated by Figure 3. The WHO maximum allowable concentration of Cd in drinking water is 0.003 mg/l WHO (1993). It was however observed that Ede and OAU water contained Cd concentrations higher than the above stated WHO limit. This gives cause for concern as the use of water high in Cd could cause adverse health effects such as renal diseases, cancer (Kjellstroem, 1986; Friberg et al., 1985a; Ogunfowokan et al., 2008) and pain in the bones (itai itai disease) (Stoeppler, 1991; Farid et al., 2006). Cadmium also has mutagenic and teratogenic effects (Friberg et al., 1985a; Fischer, 1987).

However, Zn concentrations ranged between zero and 0.0026 mg/l for Asejire, between zero and 0.0037 mg/l for Ede and from zero to 0.0035 mg/l in OAU municipal water (Figure 3). The annual mean Zn concentrations in the samples were 0.003 mg/l, 0.009 mg/l and 0.008 mg/l for Asejire, Ede and OAU waters respectively. The values of zinc obtained in this study fell below the 5.0 mg/l WHO highest desirable level for zinc in drinking water; hence the use of such water for domestic purposes may not pose any danger.

Lead is defined by United States Environmental Protection Agency (USEPA) as potentially hazardous to most forms of life, and is considered toxic and relatively accessible to aquatic organisms (USEPA, 1986). Pb concentrations ranged from zero to 0.0725 mg/l in Asejire while in both Ede and OAU municipal waters, Pb concentrations ranged from zero to 0.0668 mg/l and from zero to 0.1335 mg/l respectively (Figure 3). This resulted in annual means of 0.0107 mg/l, 0.0178 mg/l and 0.0154 mg/l Asejire, Ede and OAU municipal waters respectively. The mean lead concentrations in all the water samples analysed in this study are higher than the 0.01 mg/l recommended WHO maximum allowable concentration for drinking water. This is dangerous and can lead to behavioural changes and impaired performances in Intelligence Quotient (IQ) tests (Lansdown, 1986; Needleman, 1987).

Copper is one of several heavy metals that are essential to life despite being inherently toxic as non-essential heavy metals like Pb and Hg (Scheinberg, 1991). The annual mean Cu concentrations in the municipal water samples from the three reservoirs however are 0.0238 mg/l, 0.0315 mg/l and 0.0392 mg/l respectively in Asejire, Ede and OAU. All the water samples analysed in this study contained Cu in concentrations below the 1.0 mg/l stipulated level for Cu in drinking water by the Nigerian Federal Environmental Protection Agency (FEPA) as well as the 2.0 mg/l WHO recommended limit for drinking water. Therefore, all the water samples tested contained Cu in concentrations that may not be detrimental to consumers. The results of Cu analysis in this study indicate that the consumers of the water samples may not be exposed to the risk of brain damage, which results from excess Cu (DWAF, 1996b).

The monthly variations of mercury, manganese, nickel and arsenic in the reservoirs are presented in Figure 3. The annual mean Hg concentrations in Asejire, Ede and OAU municipal waters are 0.0588 mg/l, 0.1021 mg/l and 0.0540 mg/l respectively. It is evident that all the water samples contained Hg concentrations above the 0.001 mg/l WHO recommended limit in drinking water. Again this gives cause for great concern.

The annual mean Mn levels in the water samples are 0.0062 mg/l, 0.0017 mg/l and 0.0026 mg/l for Asejire, Ede and OAU municipal waters respectively. The WHO provisional guideline value of 0.5 mg/l for drinking water was not exceeded in any of the treated water. Since the major effect of Mn in water for domestic use is aesthetic, the likelihood of defective aesthetic state of the water samples tested therefore are slim provided iron does not pose a threat.

The Ni concentrations in the water samples ranged between zero and 0.01 mg/l for all samples from the three reservoirs. The annual mean Ni concentrations in these water samples were 0.0008 mg/l, 0.0027 mg/l and 0.0014 mg/l for Asejire, Ede and OAU municipal waters respectively. All the water samples tested contained Ni levels below the WHO guideline maximum allowable concentration of 0.02 mg/l in drinking water. Therefore the water from these reservoirs may not expose consumers to the effects of excess Ni exemplified by immune dysfunction, cardiovascular disorder and lung cancer (Scheinberg, 1991).

Arsenic concentrations in the municipal water ranged between zero and 0.0575 mg/l for Asejire, between zero and 0.0800 mg/l for Ede as well as from zero to 0.0450 mg/l in OAU municipal water. The annual mean As concentrations of 0.0189 mg/l, 0.0183 mg/l and 0.0131 mg/l were obtained for Asejire, Ede and OAU municipal waters respectively. The 0.01 mg/l WHO provisional guideline value was exceeded in all the treated water samples. This may expose consumers of such water to the risk of muscular weaknesses and cancer (Yen, 1999). The higher concentration in treated water samples may have resulted from storage or distribution systems (Scheinberg, 1991).

Conclusions

The municipal water from Asejire, Ede and Opa reservoirs have been characterized in terms of physico-chemical and microbial qualities. The results indicate that temperature, pH, solids and electrical conductivity variations in the municipal waters give no cause for concern as they were found to be within the range for unpolluted waters. The baseline dissolved oxygen in the water samples was less than the 10 mg/l-dissolved oxygen typical of unpolluted waters. The microbiological quality of all the samples gave an indication of a potential health risk for consumers. Therefore efforts should be intensified on the biological treatment of water so as to reduce the risk of intestinal infections, cholera, typhoid fever, dysentery and other impacts of poor microbiological quality of water. The annual mean concentrations of Zn, Fe, Cu, Mn and Ni were within acceptable limits; however, toxic elements like Cd, Pb, Hg and As occurred at levels that could pose a serious health risks to consumers.

The three waterworks need to upgrade and improve their treatment performances especially on the parameters that affect consumers adversely to ensure sustainable use of their municipal water for drinking and reduce incidences of water-borne diseases.

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