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Quantification of metals, physicochemical and microbiological properties of consumed sachet/surface waters in Ayetoro Community, Ogun State, Nigeria

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Abstract

This study quantified some trace and heavy metals, assessed the physicochemical and microbiological qualities of sachet and surface drinking waters in Ayetoro Community, Nigeria while comparing with other studies, national and international standards for drinking water. The concentrations of calcium, magnesium and iron (1.25 – 6.03 mg/l, 1.33 – 17.31 mg/l, 0.14 – 0.62 mg/l; respectively) in all samples which were below and within the WHO limits, while manganese, zinc, cadmium and lead (0.12 – 0.47 mg/l, 10.51 – 45.50 mg/l, 0.011 – 0.049 mg/l. 0.25 – 2.55 mg/l) quantities in the thermally treated river water samples still exceeded the maximum permissible limits. The physicochemical parameters were within acceptable limits. The documented temperature and pH values ranged between 23.6 – 29.5 °C and 6.72 – 8.48; respectively. The lowest and highest values total dissolved solid (TDS) were 50 and 432mg/l, respectively, while turbidity and electric conductivity of the water samples ranged between 0.63 – 46.12 NTU (nephelometric turbidity units) and 74.83 – 343.13 µS/cm; respectively. The total coliform count (TCC) and fecal count (FC) values of the samples were higher when compared to standards. Despite the fact that the physicochemical parameters were within acceptable limits when compared to the standards, the drinking water sources still pose health risks. Consequently, improved water treatment and processing systems are needful to reduce the alarming critical values to a more acceptable limit.

1. Introduction

Water is an essential part of human nutrition and it is required for the maintenance of personal hygiene, food production and prevention of diseases [1]. A reliable supply of clean wholesome water is highly essential in a bid to promoting healthy living amongst the inhabitants of any defined geological region [2, 3]. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life [4, 5], and it is goal 6 of the sustainable development goals (SDGs) [6, 7].

The water pollution by heavy metals has therefore become a question of significant public and scientific concern in the light of the evidence of their toxicity even at low concentrations to human and biological system [8, 9]. These metals among others includes: lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), silver (Ag), chromium (Cr), copper (Cu), iron (Fe), platinum (Pt), manganese (Mn) and arsenic (As) are a few number metals to mention that pose a threat to human health through drinking water [10, 11, 12].

Developing countries; including Nigeria had been confronted with issues regarding water supply systems and access to potable drinking water, which is a global concern that calls for immediate action [13, 14]. Accessibility to quality drinking water by all citizens who are deprived will serve as the breaking point of poverty alleviation in most developing countries, especially in Africa, where chunk of their national budgets are allotted to treat preventable waterborne diseases [15]. Notably, access to reliable drinking water is recognized by United Nations as a human right.

However, municipal, industrial, and agricultural waste enters the water, causing biological and chemical contaminants, including heavy metals which go into the water resources [16]. Noteworthy, some of these metals are essential as micronutrients, their high concentrations in the food chain hence leads to toxicity and environmental impacts, endangering aquatic ecosystems, man, animal and hindered other purposed uses [17 – 21].

Groundwater is an important source of drinking water for humans, it contains larger percentage of the available freshwater resources and it is an important reserve of good quality water [22]. Groundwater has extensively being exploited through the construction of boreholes and hand dug wells for domestic, agricultural, and industrial usages. The rapid population growth and urbanization as well as led to an increase in demand and exploration for potable water, hence exposing groundwater resource to the risk of contamination [23, 24].

Surface water (rivers) is also the most vital freshwater resources in the world, but its probability is however being truncated by increasing human development, industrialization and population growth which has exerted alarming and diverse pressures on the quality, quantity and access to water resources [25]. The presence of heavy metals as a result of industrial activities around the river and consistent discharge of untreated liquid waste into the river which affects the water quality adversely and mostly the dwellers downstream who utilizes it unconsciously [26]. Also, toxic chemicals and heavy metals enters rivers through industrial and anthropogenic activities of urban settlement around the drainage basin of rivers [27], and wet and dry deposition of atmospheric salts, water-soil and water-rock interaction [20].

There had however been increasing evidences linking heavy and trace metals toxicities to the incidence of cognitive impairments, especially in children, deficiencies of some essential nutrients in the human body as well and cancers of all sorts [28 – 31]. High concentrations of lead, arsenic and other heavy metals had earlier been reported to affect the nervous system and kidneys, and may cause reproductive disorders, skin lesions, endocrinal damage, and vascular diseases [17]. These ultimately leads to decreased immunological defenses, disabilities associated with malnutrition, intrauterine growth retardation, impaired psychosocial faculties, and high prevalence of upper gastrointestinal cancer rates [32].

Nonetheless, groundwater samples (from hand dug wells and bore holes) and surface water (river) distributed in the study area shows some deviation from the normal physical characteristics (colour, taste among other parameters) especially, when examined physically. Moreover, there has been no record of any serious documented research work (published work) carried out to assess the quality of the groundwater sources (bore holes and hand dug wells) and surface water sources in the study area. Therefore, it is essential to determine the quantity of metals concentration in consumed sachet waters (via groundwater) and surface waters (river and its thermally treated samples) in Ayetoro, Yewa North Local Government Area, Ogun State, Nigeria.

2. Material and Methods

The study was conducted in Ayetoro, which lies on the latitude 7° 12’N and longitude 3° 3’ E as shown in Figure 1. This area is 90 and 120m above sea-level, with average annual rainfall of 1,909.30mm, with an undulating surface drained mainly by Rori and Ayinbo rivers [33]. The town is also the administrative seat/headquarters of Yewa North Local Government Area in Ogun State, Nigeria.

As described by American Public Health Association (APHA) [34], a total of six (6) sachet water (SW) samples (coded as; SW1, SW2, SW3, SW4, SW5 and SW6). They were collected from sachet water producing companies (with National Agency for Food and Drug Administration and Control (NAFDAC) registration numbers printed on packaging materials) resident in study area; sourcing its water from boreholes. Surface waters for this study were collected from a flowing river at two (2) protected drinking water collection points 1 and 2 (coded as; RW1 and RW2; respectively) with coordinates 7° 14’N 3° 1’E and 7° 13’N 3° 2’E; respectively in August 2019, as indicated in Figure 2. These surface waters were further thermally treated by boiling at 100 °C for 30 min (coded as; TW1 and TW2), giving a total of ten (10) samples and kept for further analysis.

Analysis including pH, temperature, colour, conductivity and turbidity were conducted at the site of surface water samples collection abiding with standard protocols and methods of APHA [34] using appropriate calibrated standard instruments: a pH-temperature meter (model HI 98130 HANNA, Mauritius), portable water photometer (model HI 96727 HANNA, Mauritius), conductivity meter (model HI 98130 HANNA, Mauritius) and a turbidity meter (model 2100P Turbidimeter HACH, Colombia, USA); respectively. Other samples were tested in the laboratory. The measurements of total dissolved solid (TDS) in water samples were carried out according to the standard methods of APHA [34] and Sawyer *et al.* [35] by the filtration process. An atomic absorption spectrophotometer (AAS, Unicom 969) was used to determine the trace and heavy metals based on standards approved by APHA [36]. The load of total coliform bacteria was determined and enumerated by millipore filtration method as outlined in APHA [34], and as per the procedure by Krishnan *et al.* [37]. Fecal coliform in water samples were analyzed at elevated incubation temperature of 44.5 ± 0.2 °C using m-Endo agar as described by Obeta [38].

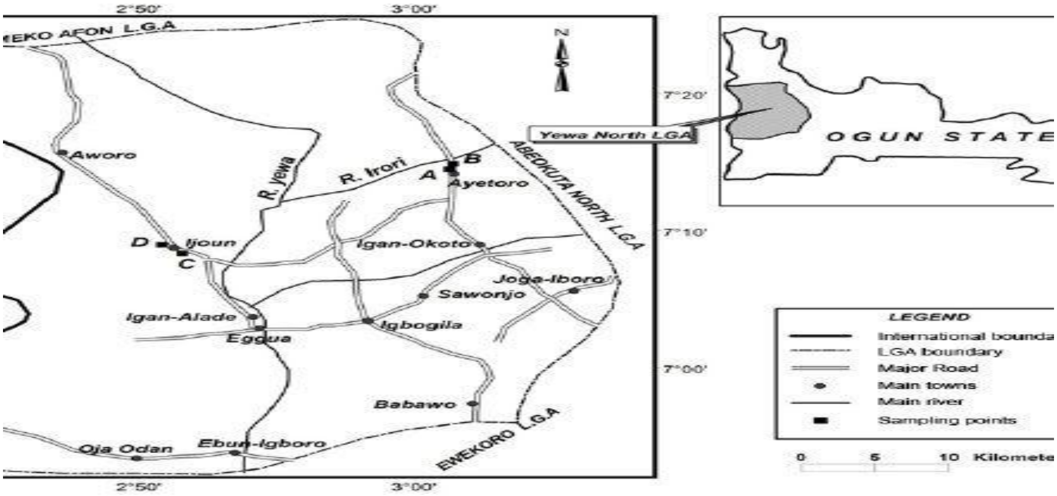

Figure 1 : Map of the area of study
Source: Salawu and Odaibo (2014)

Figure 2 : Map of the area of study
Source: Google Maps (2019)

3. Results and discussion

The results of varying concentrations of metals (trace and heavy) determined in the water samples are as shown Table 1, while Table 2 reveals physicochemical and microbiological analysis of all samples.

Samples 1 – 8 in the order of SW1, SW2, SW3, SW4, SW5, SW6, RW1 and RW2 were tested for trace metals, while heavy metals determination was conducted on samples 9 and 10 (TW1 and TW2; respectively).

3.1 Trace and heavy metals determination

The calcium (Ca) concentrations obtained in samples 1 – 8 ranges from 1.25 – 6.03mg/l with significant difference ($p < 0.05$). Sample 2 (SW2) had the least while sample 7 (RW1) had the highest value. Calcium concentrations in the water samples were within and below the maximum limit (200mg/l) of WHO [17]. Consequently, the water samples are suitable for drinking. Calcium content levels in water indicate perceived water hardness. Heaney [39] reported that the consumption of calcium in high-calcium mineral water can potentially account for total daily calcium intake, which functions much like a supplement. Notably one litre of water containing approximately 300 mg of calcium per litre will provide calcium quantities equal to one dairy (milk) serving. Also, consumption of 972 mg of calcium in 2 litres of water just prior to and during exercise completely eliminated the increase in osteoclastic bone resorption (calcium loss).

Magnesium (Mg) concentrations obtained from samples 1 – 8 varied from 1.33 – 17.31mg/l with significant difference ($p < 0.05$). Samples 5 and 8 had the least and highest values; respectively. The records of Mg in this study was below the WHO [17] permissible standard (150mg/l) for drinking water. The values in this study were higher than those reported by Rahmanian *et al.* [40] in drinking water samples of Perak state, Malaysia. IOM [41] reported magnesium intake can be significantly influenced by water consumption with an estimated 40–100 mg/day through drinking water.

In this study, concentrations of calcium and magnesium samples however compared favourably with European bottled waters values which are usually within the ranges of 1.5 – 600 mg/l and 0.5 – 90 mg/l; respectively [42].

Table 1: Concentrations of metals (trace and heavy) determined in the water samples

Sample		1	2	3	4	5	6	7	8	9	10
Sample name		**SW1**	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**RW1**	**RW2**	**TW1**	**TW2**
Trace Metals (mg/l)	Calcium	3.18	1.25	1.81	3.15	2.31	2.11	6.03	3.39	ND	ND
	Magnesium	1.45	2.11	1.73	9.41	1.33	2.98	11.57	17.31	ND	ND
	Sodium	9.11	7.52	9.45	8.65	8.27	7.91	9.81	5.95	ND	ND
	Potassium	1.03	0.95	1.15	0.92	1.12	1.32	1.39	0.95	ND	ND
	Iron	0.41	0.52	0.37	0.45	0.62	0.37	0.29	0.14	ND	ND
Heavy Metals (mg/l)	Manganese	ND	ND	ND	ND	ND	ND	ND	ND	0.12	0.47
	Zinc	ND	ND	ND	ND	ND	ND	ND	ND	10.51	45.5
	Cadmium	ND	ND	ND	ND	ND	ND	ND	ND	0.011	0.049
	Cobalt	ND	ND	ND	ND	ND	ND	ND	ND	0.015	0.04
	Lead	ND	ND	ND	ND	ND	ND	ND	ND	0.25	2.55

ND – Not determined

Sodium (Na) concentrations obtained from this study revealed that samples 1 – 8 ranged between 5.95 – 9.81mg/l. Most water supplies contain less than 20 mg of sodium per litre, however some countries levels can exceed 250 mg/litre, and a total daily intake of 120–400 mg meets the required daily needs of growing infants and young children, while for adults 500 mg. Inclusion of water containing high levels of sodium to solid food can as well intensify the effects when such foods are ingested [17].

Potassium (K) concentrations of samples 1 – 8 varied between 0.92 - 1.39mg/l with significant difference ($p < 0.05$). Samples 2 and 8 however had similar values (0.92mg/l) and were not significantly different. The use of potassium chloride as a water softener is an indicative significance to the intake of potassium when compared with the amount that would be typically consumed in drinking-water, even after water treatment for its hardness levels can generally be considered acceptable if intake does not exceed 2.7 mg/kg in body weight per day (assuming consumption of 2 litres of water per day by a 60 kg adult) [43]. However, dietary reference intake values (as adequate intake) range from 0.4 – 4.7 g/day from infancy through to adulthood [44].

Iron (Fe) concentrations levels of samples 1 – 8 ranged between 0.14 – 0.62mg/l. Iron concentrations in all samples were within the values of permissible limits of WHO [17] guidelines for drinking water, exclusively samples 7 and 8 were lower and fell within the maximum limits (0.3mg/l) of WHO [17] guidelines for drinking water. The values of the study were lower than those reported by Rahmanian *et al.* [40] and Edokpayi *et al.* [45] in drinking water samples of Perak state, Malaysia and Mvudi River, South Africa; respectively. A provisional maximum tolerable daily intake (PMTDI) of 0.8 mg/kg of body weight was established in 1983 [46]. An intake of 0.4–1 mg/kg of body weight per day is unlikely to cause adverse effects in healthy persons [47]. Iron taste is often not conspicuous at concentrations below 0.3 mg/litre, but the average lethal dose of iron is 200–250 mg/kg of body weight [48].

The manganese (Mn) concentrations obtained from samples 9 and 10 were 0.12mg/l and 0.47mg/l; respectively. Manganese concentrations in the two water samples were above maximum limit (0.1mg/l) of WHO [17] but within the permissible limit (0.5mg/l) of WHO [17] standard. The values of the study were higher than those reported by Edokpayi *et al.* [45] on Mvudi River, South Africa. IOM [49] however recommended adequate intake levels for manganese at 2.3 mg/day for men and 1.8 mg/day for women, while between 0.003 – 2.3 mg/day from infancy with increases to adolescents and adults. Manganese in drinking-water will be objectionable in a physical assessment by water discoloration if its deposit in water remains, due to human activities which are prime factors for the manganese contamination in water, and overexposure to certain levels of manganese results to “Parkinson-like syndrome”, including weakness, anorexia, muscle pain, apathy, slow speech, and slow, clumsy movement of the limbs [17]. Oxidation and filtration are usually adequate to achieve a manganese concentration of 0.05 mg/l in drinking-water.

The zinc (Zn) concentrations recorded for samples 9 and 10 were 10.51 mg/l and 45.50 mg/l; respectively. The zinc concentrations recorded from both samples were within the WHO [17] maximum limit of 75mg/l while samples 9 and 10 were slightly and above; respectively the permissible limit (10mg/l) of WHO [17]. The values of the study were higher than those reported by Rahmanian *et al.* [40] and Edokpayi *et al.* [45] in drinking water samples of Perak state, Malaysia and Mvudi River, South Africa; respectively. Zinc is an important element that plays a vital role in the physiological and metabolic process of many organisms, which at higher concentrations of zinc can be toxic to organisms [50]. The average daily intake of zinc of 5 – 22 mg stable with a recommended dietary allowance for adult men being 15 mg/day, adult women 12 mg/day, infants mixes 5 mg/day, and for adolescents 10 mg/day [48, 51, 52]. A major consequence of the chronic ingestion of zinc is zinc therapy (150–405 mg/day) for coeliac disease and sickle cell anaemia [52, 53]. Joint FAO/WHO Expert Committee on Food Additives (JECFA) [54] however recommended a dietary requirement of zinc of 0.3 mg/kg of body weight and a provisional maximum tolerable daily intake (PMTDI) of 1.0 mg/kg of body weight.

Cadmium (Cd) concentration levels obtained for both samples 9 and 10 were 0.011mg/l and 0.049mg/l. The Cd concentrations of TW1 and TW2 exceeded the WHO [17] maximum limit of 0.01mg/l for drinking water. Cadmium concentrations in unpolluted natural waters are usually below 1 μg/l [55]. The values of the study were higher than those reported by Rahmanian *et al.* [40] and Edokpayi *et al.* [45]. The provisional tolerable weekly intake (PTWI) of 7 μg/kg of body weight was announced by JECFA [56] and reaffirmed by JECFA [57] sustained by JECFA [58]. The estimated lethal oral dose for humans is 350 – 3500 mg of cadmium, with kidney being the most sensitive organ at chronic oral exposure. More severe cases of cadmium damage accounts for the glomeruli and resorption of minerals from bone, which can result in the development of kidney stones and osteomalacia [17]. The presence of cadmium in drinking water simulates oestrogen which gives attention to public health practitioners considering that it is a very important hormone causing menstrual irregularity with adverse effects on the female reproductive health [59]. At very low exposure levels, cadmium in the body system also causes adverse health effects such as kidney damage, bronchitis, osteomalacia (soft bones) and other non-cancerous diseases that include loss of sense of smell and taste, fibrosis, shortness of breath, skeletal effects, lumbago, hypertension, tubular proteinuria, and cardiovascular diseases as well as damage to DNA and the immune system, and enhances the development of cancer [60].

The cobalt (Co) concentrations in samples 9 and 10 were 0.015mg/l and 0.04mg/l; respectively. Cobalt is rarely detected in drinking-water, but has a low concentration in drinking-water ranging from 0.1 – 5 μg/l [61]. There are no long-term studies of humans ingesting cobalt, however short-term (22 days) ingestion of cobalt at 150 mg/day in human volunteers produced polycythaemia and increased haemoglobin with minimal risk level of 50 μg/kg body weight per day [62].

The lead (Pb) concentrations in samples 9 and 10 are 0.25mg/l and 2.55mg/l; respectively. The Pb levels in samples exceeded the WHO maximum limit of 0.05 mg/l, even after thermal treatment. The values of the study were higher than those reported by Rahmanian *et al.* [40] and Edokpayi *et al.* [45]. Lead is one of the most significant toxicants of the heavy metals and the inorganic forms are absorbed through ingestion by food and mostly water, and inhalation [63]. The toxicity of Pb has no nutritional value to living organisms and no amount of Pb is considered safe in drinking water. High concentration of Pb impairs the proper functioning of the reproductive and nervous systems, including kidney damage, high blood pressure and anemia [17, 64]. Even at very low concentrations, Pb is a threat to public health, because it usually builds up in the body especially in children under the age of six leading to mental and physical retardation [65].

3.2 Physicochemical Analysis

The physicochemical analysis of samples revealed that the pH of the sample ranges from 6.72 – 8.48. The pH of samples was all within the WHO [17] and NDWQS [66] guidelines for drinking water which are between 6.5 – 8.5 and 6.5 – 9; respectively. The pH values were comparable to values recorded by Rahmanian *et al.* [40] and Wang *et al.* [67] for drinking water sources. Also, pH values less than 6.5 has been reported to cause corrosion and the subsequent release of metals such as lead, zinc, and copper from pipes and plumbing fixtures into water leading to toxicity to humans over a period of ingestion [68]. Temperatures of the samples were between from 23.6 – 29.5 °C, and were within the WHO guideline for drinking water Maximum Permissible Level (40 °C) by WHO [69] and comparable with values reported by Foka *et al.* [70] for borehole waters, but higher than values reported by Sila [71] for quality of water sources in Kenya. The colour of water samples ranged between 2 – 12 TCU (True Colour Units). All samples in this study had better colour values than those reported by Sila [71] for quality of water sources in rural settings and below the values (15 TCU) of NAFDAC and National Drinking Water Quality Standard (NDWQS) [72]. The measured conductivity of water samples in this study ranged from 74.83 – 343.13 μS/cm. Sample 3 was the least while the highest conductivity was sample 7; respectively. The values in this study were below the maximum allowable level of conductivity (1000 μS/cm) [66], and comparable to the values recorded by Rahmanian *et al.* [40] in drinking water samples. Conductivity has no direct implication on human health [73 – 75].

The turbidity of sampled water in the study area were fairly low, and values of samples ranged from 0.63 – 46.12 NTU (nephelometric turbidity units). Samples 7 and 8 were above maximum permissible level (25 NTU) and were also higher than all other samples which were below highest desirable levels (5 NTU) [66, 76]. The values of study compared favourably with the study of Foka *et al.* [70] for borehole waters, and fairly with the reports of Rahmanian *et al.* [40], Yasin *et al.* [77], and Sila [71].

The total dissolved solids (TDS) of samples values ranged from 50 – 432mg/l. Total dissolved solids (TDS) indicate the amount of chemical substances dissolved in the water, which at increased levels in excess of 1500 mg/l (Maximum Permissible Level) decreases palatability and may produce a bad taste [17]. The values recorded in this study for samples 1 – 6 comparably with those of Rahmanian *et al.* [40], while samples 7 – 10 were comparably with the values reported by Yasin *et al.* [77] and Foka *et al.* [70]. The taste, odour and appearance of samples 1, 2, 3, 4, 5 and 6 in this study area such as were unobjectionable and clear, while the result for samples 7, 8, 9 and 10 objectionable and unclear.

Table 2: Physicochemical and microbiological analysis of all samples

Sample	1	2	3	4	5	6	7	8	9	10
Sample name	**SW1**	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**RW1**	**RW2**	**TW1**	**TW2**
pH	6.87	6.83	7.13	6.92	6.97	6.72	7.55	7.64	8.25	8.48
Temperature (°C)	23.6	23.9	24.7	25.1	25.6	25.4	26.6	26.6	29.3	29.5
Colour (TCU)	2	2	2	2	2	2	10	12	8	5
Conductivity (µS/cm)	74.85	91.32	74.83	87.33	85.93	80.44	343.13	302.11	199.43	169.12
Turbidity (NTU)	0.71	0.63	0.91	0.88	0.78	0.81	43.33	46.12	13.11	14.28
Total Dissolved Solid (mg/l)	52	53	50	51	52	51	427	432	315	333
Taste	U	U	U	U	U	U	O	O	O	O
Odour	U	U	U	U	U	U	O	O	O	O
Appearance	C	C	C	C	C	C	O	O	O	O
Total coliform (CFU/100ml)	6	3	5	7	7	6	38	43	13	16
Fecal coliform (CFU/100ml)	ND	ND	ND	ND	ND	ND	21	24	6	5

U – Unobjectionable (Acceptable) **O – Objectionable (Unacceptable)** **C – Clear** **ND – Not determined**

3.3 Microbiological Analysis

Total coliform count (TCC) obtained from samples 1 – 10 varied from 3 – 43 CFU/100ml with significant difference ($p < 0.05$). Samples 2 and 8 had the least and highest values; respectively. However, WHO [76] reported that total coliform bacteria must not be detectable in any 100 mL sample. The values in this study were less to the TCC reported by Onyango *et al.* [78], but fairly comparable to counts reported by Yasin *et al.* [77] for tap water, protected wells and protected springs and the study of Foka *et al.* [70] for borehole waters, except those stored in metallic tanks, while precisely samples 1 – 6 were below the expected values expected for NDWQS (≤ 10 CFU/100ml) [72]. Fecal count (FC) obtained from samples 7 – 10 varied from 5 – 24 CFU/100ml with significant difference ($p < 0.05$). Samples 9 and 10 compared favourably with counts reported by Yasin *et al.* [77] for protected wells and protected springs, while samples 7 and 8 were higher. Other reports on isolation of coliforms from potable borehole water systems were those of Isa [72], Ikeme *et al.* [79], Palamuleni and Akoth [80], Ugbaja and Otokunefor [81] and Woke and Bolaji [82] which were as a result of proximities to a source of waste water sewage systems.

Conclusion

The determined values of water quality parameters such as pH, temperature, conductivity, turbidity and TDS from all samples collected in Ayetoro Community, Nigeira were found to be within the recommended limits and fair for consumption. Notably, concentrations of metals were found some to be below the standard maximum concentrations and comparable to samples from other geographical locations. The quality of sachet drinking waters indicates good reasons for their consumption, while domestic thermal treatment of river water at 100 °C helpfully aided its acceptability, except matters regarding metal concentrations and coliform counts which will likely pose any adverse effects on consumers; else sophisticated water processing methods are employed. The levels of metals also vary at the two sampling river water points, subject to anthropogenic activities around the drainage basin of rivers. However, it is a good step in the right direction to investigate the *in vivo* effects when these samples are consumed for a longer period of time via animal experiments, and as well including human body fluids, in order to assess the overall water quality.

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