COMPARATIVE ASSESSMENT OF THE POTABLE QUALITY OF WATER FROM INDUSTRIAL, URBAN AND RURAL PARTS OF LAGOS, NIGERIA

Afolabi, T. A.[1],*, Ogbuneke, C. C.[2], Ogunkunle, O. A.[3], Bamiro, F. O.[1]

[1] Department of Chemistry, Federal University of Agriculture, Abeokuta, Nigeria.
[2] Department of Chemistry, University of Ibadan, Ibadan, Nigeria.
[3] Department of Chemistry, Obafemi Awolowo University, Ile-Ife, Nigeria.
* Corresponding Author
E-mail: niyiafo@yahoo.com (T.A. Afolabi)
Telephone: +234 803 5718657
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ABSTRACT

The physicochemical properties metal concentration of drinking water from different sources in Lagos area of Nigeria were determined with a view of comparing the effects of industrialisation, population density and urbanisation on the water quality from Lagos metropolis (Lagos Centre) and Ikorodu area (a relatively less industrialized and urbanized town of Lagos State) as a case study. The different sources of drinking water considered were wells, boreholes, surface water and pipe borne water. The results revealed the water to be generally acidic (pH less than 7 ranging from 6.29 to 6.90) with mean values of 6.62 ± 0.31 and 6.49 ± 0.18 for Lagos Centre and Ikorodu area respectively, with significant difference in the pH of the well, tap, and borehole waters. In the urban Lagos Centre, well water had the highest DO, BOD, and acidity; the borehole water had the highest EC and TDS; while the pipe borne water had the least EC and TH. Similar result was reported for the rural Ikorodu area. The 495 and 399 μS/cm mean conductivity values for the well water from Lagos Centre and Ikorodu area respectively were significantly higher than that of the borehole, surface, and pipe borne water for both area. The physicochemical properties such as total solids (TS), total suspended solids (TSS), dissolved oxygen (DO) and alkalinity were generally significantly higher than the WHO, EU & NIS standard limits, with the values for Lagos Centre significantly higher than that of Ikorodu area. The Pb, Ni, Mg, and Fe concentrations exceeded the permissible limits set by WHO, EU and NIS for all the samples, with the Lagos Centre having the highest values. However, Cu, Zn, Na, Cr, and Ca concentrations were within the permissible limits with the Lagos Centre samples having the highest values. Cd was not detected in any of the samples. This research has revealed the adverse effect of industrialisation, high population density, rapid urbanisation, etc., on the potable water sources in Lagos State of Nigeria, which could result in serious health hazards but with more pronounced negative implications on the Lagos Centre.

Keywords: Borehole Water, Pipe Borne Water, Surface Water, Effluent, Leachate.

INTRODUCTION

Water is one of the most vital natural resources necessary for the existence of life. In most urban cities in most countries of the world, including Nigeria, it is the duty of the government to provide potable water. Most often the responsibility is not adequately discharged, causing the inhabitants of those cities to look elsewhere to meet their water needs. The alternative may be unwholesome (Okoye and Adeleke, 1992). These alternatives include sourcing for groundwater via borehole or well, and stream/river water.

Groundwater has long served as a source of drinking water and it is still very important today. The development of ground water has provided great socio-economic benefits to humanity. Globally, groundwater is estimated to provide about 50% of current drinking water supplies. Groundwater is a reliable source of water supply, because it is often unpolluted due to restricted movement of pollutants in the soil profile (Lamikanra 1999; Lamb, 1985). Although most groundwater is of high quality, at some locations, it is becoming increasingly difficult to maintain the purity of groundwater. One of the major sources of pollution of groundwater is saltwater intrusions. Others include seepages from underground storage tanks, oil wells, septic tanks, landfills and agricultural leaching (Adewuyi et al., 2010). Shallow and permeable water table aquifers are most susceptible to contamination (Moody, 1996). The potential of such water to harbour microbial pathogens and cause illness is well documented for both developed and developing countries (Wright *et al.,* 2004). Introduction of pollutants into the natural water usually occur directly through point sources (septic tanks, disposal sites, etc,) near the ground water or indirectly through non-point source when already polluted water in the area enters into the freshwater body by lateral or side movement (Hammer, 1986).

Water pollution may results in transmission of infectious diseases. The implications of waterborne bacteria and virus infection include polio, hepatitis, cholera, diarrhoea, typhoid etc (Kukkula *et aI.,* 1997). Thus, contamination of drinking water from any source is of primary concern due to the danger and risk of water diseases. The World Health Organization *(WHO)* reported that 40% of deaths in developing nations occur due to infections from water related diseases and an estimated 500 million cases of diarrhoea, occurs every year in children below 5 years in parts of Asia, Africa and Latin America (WHO 2006; 2010).

Water that has good drinking quality is of basic importance to human physiology and human's continued existence relies very much on its availability (Oketola *et al.*, 2006; Olajire and Imeokpara, 2001). According to Davis and De-Wiest (1966), the standard for drinking water can be attributed to two main criteria, namely: the presence of objectionable taste, odour and colour and the presence of substances with adverse physiological effects. The extent of treatment needed therefore is determined by the quality of the raw water source (Adejuwon and Mbuk, 2011; Macrea *et al.,* 1993). Therefore, water has to meet up with certain physical, chemical and microbiological standards, that is, it must be free from diseases producing micro-organisms and chemical substances, perilous to health before it can be termed potable (Ihekoronye and Ngoddy, 1985).

Though, much of the land area of Lagos State is covered by water, getting a clean drinking water poses a major challenge. It is almost impossible to get drinking water from the large volume of surface water found in Lagos. This is largely due to salinity of the water bodies and also pollution by anthropogenic activities. As a result of immense industrialization and high population density, groundwater is heavily relied upon in Lagos metropolis to serve as an alternative source of water where surface water is seriously polluted. The continued reliance on ground water has resulted in its decline in quantity and quality.

Contamination of drinking water supplies from industrial waste is as a result of various types of industrial processes and disposal practices. Industries which use large amount of water in their processes (like steam production as solvent for washing purposes, as a coolant, for waste disposal practices, finishing operations, etc) including chemical manufacture, steel plants, battery industries, metal processes, textile manufacturing, tanneries etc (David and Brad, 1998). There are reports that most oil terminals and gasoline stations in Lagos lack effluent treatment plants and as a consequence, the oil percolate to the groundwater in the area (Egereonu and Odumegwu, 2006), this is potentially dangerous.

The objective of this research therefore is to investigate the quality of water consumed in Lagos and its surroundings with regards to human population and level of pollution in the area. The research was based on the three popular sources of drinking water in Lagos namely; boreholes, well-waters and river/stream. A comparative study of the extent and effect of population on the different sources of potable waters in the Lagos Centre (urban, industrialised and densely populated area) and Ikorodu area (less industrialised, less populated off-town area) was also carried out.

The result obtained in this work would show the effect of industrialization and urbanization and also that of pollution on the drinking water quality in Lagos State, this would give an insight to the steps required to improve the water quality and check the uncontrolled pollution in the affected areas.

MATERIALS AND METHODS

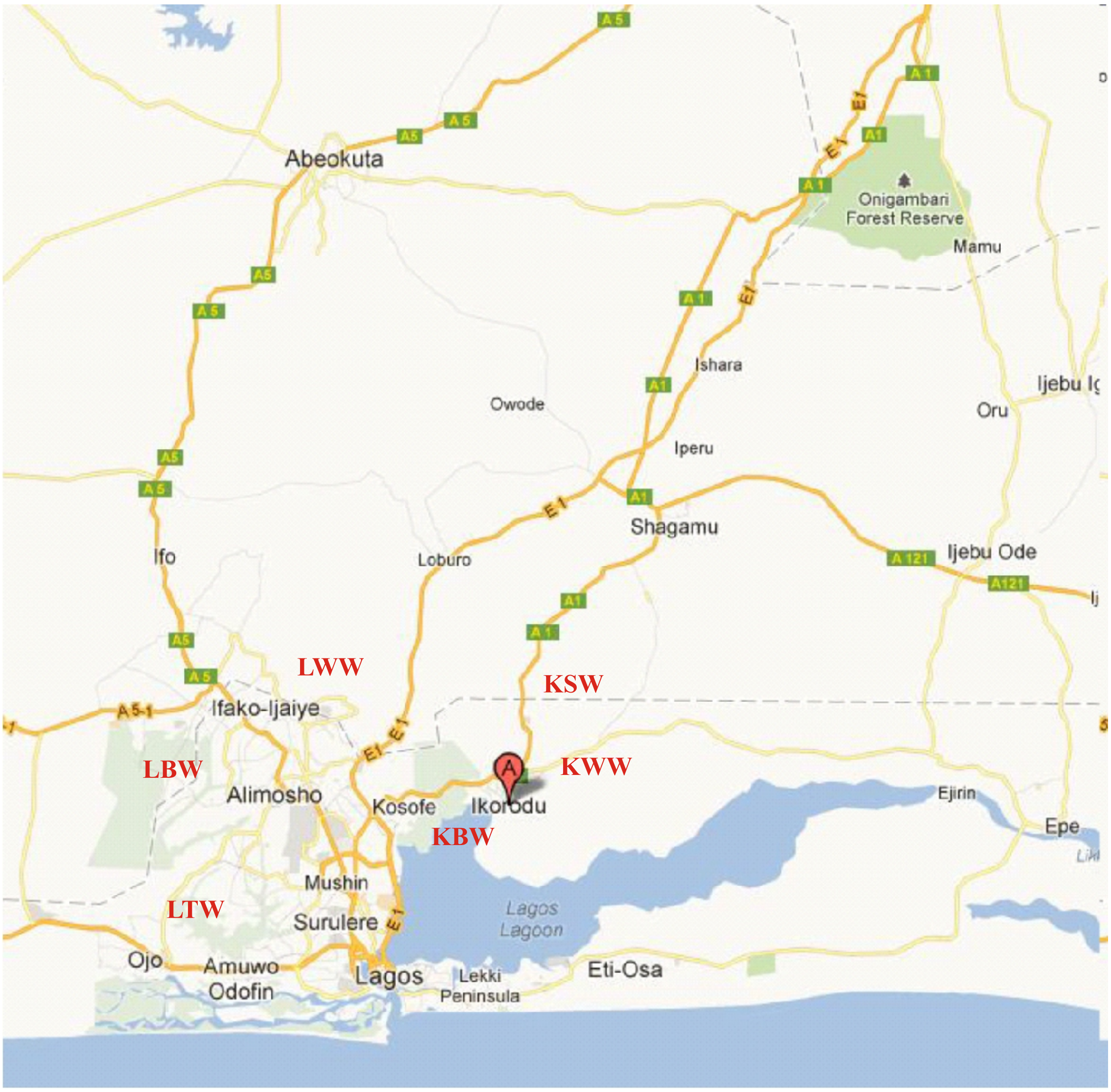
Site Description

Lagos State is the commercial and industrial nerve centre of Nigeria. It is boarded in the south by the Atlantic Ocean, in the north and east by Ogun State and in the west by Republic of Benin. It occupies an area of about 3,577 sq km with a population of about 14 million. About 70% of the industries in Nigeria are located in Lagos State and 80% of the population resides in the metropolitan (central) Lagos, making the state the most urbanized and industrialised State in Nigeria (Longe and Williams, 2006).

Ikorodu is one of the few areas of Lagos State that is of relatively low population, less developed and less industrialised (when compared with the Lagos Centre). It is located between longitudes 004° 12' - 004° 47' E and latitudes 07° 15' - 07° 36' N. The area falls within the high forest region whereas the drier Northwestern part (Sokoto, Kebbi, Zamfara States) is of the Guinea Savannah (Adejuwon and Mbuk, 2011). Ikorodu area is less developed and less industrialized than Lagos Centre.

Sampling and Sample Collection

The study area was grouped into two distinct categories as: Lagos Centre (which comprised of the industrialised, densely populated, and developed part of Lagos, Nigeria) and Ikorodu area (which is on the outskirt of Lagos, is less populated, less developed, and less industrialised). The sampling points for each area are shown in Fig 1.



Source: Google map data (www.maps.google.com).

The sampling points: LTW - Lagos Centre Well Water; LBW - Lagos Centre Borehole Water; KWW - Ikorodu Well Water; KBW - Ikorodu Area Borehole Water; KSW - Ikorodu Area Surface Water.

Fig 1: Map showing the sampling points at Lagos Centre and Ikorodu area.

Lagos Centre;

LWW (*Well Water* - Pooled) - collected from 7 areas: i.e Baruwa Ayobo, Abuleegba dumpsite surroundings, OlusosunOjota, Ilupeju industrial area, Solus dumpsite LASU-Igando road, Surulere LG swampy areas, Ijegun pipeline environs.

LBW (*Borehole Water* - Pooled) - collected from Baruwa- Ayobo, Abuleegba dumpsite surroundings, Olusosun-Ojota dumpsite, Ilupeju industrial area, Solus dumpsite LASU - Igando road, Surulere swampy areas, Ijegun pipeline environs.

LTW (*Pipe Borne Water* - Pooled) - Obtained from Ketu area, Baruwa- Ayobo, Abuleegba surroundings, Ojota, Surulere LGA, Ijegun-Ikotun area, Ikeja.

Ikorodu area*:*

KWW (*Well Water* - Pooled) - collected from 7 different areas which includes Owode, Ogolonto, Fasheun Estate, Orile Idera, Etunrenren road, CAC/Lagos road, Majidun.

KBW (*Borehole Water* - Pooled) - Obtained from Owode, Ogolonto, Fasheun Estate, Orile Idera, Etunrenren road, CAC/Lagos road, Majidun.

KSW (*Surface Water*) - obtained from 'Etunrenren' streams.

Sample Collection and Preservations

The samples for this study were collected from the sampling points indicated above over a period of three weeks. At each sampling point, water temperature and pH were measured immediately, while another sample was taken for the physicochemical properties. Plastic bottles pre-treated with dilute HNO_3 and thoroughly rinsed with distilled - deionized water were used for the collection of samples for determination of metals. All materials that came in contact with the samples and sample containers were thoroughly washed and rinsed with 1:1 nitric acid and distilled water. In order to minimize the adsorption of metals onto the container walls, 5mL concentrated HNO_3 was added per litre of samples at the time of collection (APHA, 1985). The samples were stored in the refrigerator prior to analysis.

Physicochemical Properties Determination

The total solids (TS) was determined as follow: 50mL of well-mixed water sample was evaporated to dryness on a boiling-water bath in a previously heated, cooled and weighed evaporating dish. The residue was dried at 105°C for 2 - 3 hours in an oven. This was cooled in a desiccator and weighed. The total solids (mg/L) was determined as the ratio of the solid residue to the volume of water.

The total suspended solids (TSS) was determined as follow: 50mL of the water sample was vacuum filtered through a glass-fibre filter paper, dried in an oven at 105°C for 1hr, cooled and weighed. TSS is the ratio of the suspended solids to the volume of water in mg/L. The total dissolved solids (TDS) is the difference between the total solids (TS) and total suspended solids (TSS).

The dissolved oxygen (DO) was determined by iodometric (azide modification) method, while the dilution method was used for the determination of the Biochemical Oxygen Demand (BOD) using the procedure of APHA (1985). The total hardness (TH) was determined by EDTA titrimetric method (APHA, 1985).

The alkalinity (in mg $CaCO_3$/L) of the water samples was determined by titrimetric method using 0.2 g Na_2CO_3 stadardized with 1M HF. The total acidity (in mg $CaCO_3$/L) was also determined by titrimetric method using 0.02M NaOH.

The nitrate content of the water sample was determined as follow: 10ml of the sample was mixed with 2 ml of 1M NaCl in cold-water bath, and thoroughly mixed with 10ml of 1M H_2SO_4 acid, followed by 0.05mL brucine sulfanilic acid reagent, the tube was then placed in a water bath at 95°C for 20 mins before cooling to room temperature. An aliquot of the solution was measured at 410 nm using distilled water as blank. The concentration of the nitrate was calculated by the equation:

$$\frac{mg}{L}\ N = \frac{Absorbance\ of\ sample\ X\ Conc.std.}{Absorbance\ of\ Standard} \quad (1)$$

$$\frac{mg}{L}\ NO_3 = \frac{mg}{L}\ N\ X\ 4.43 \quad (2)$$

The sulphate concentration was determined as follow: 20ml of NaCl - HCl solution was added to 100 ml of the water sample with constant stirring, while 0.3g of $BaCl_2$ was added. The absorbance of an aliquot portion was determined at 420nm after 3mins. A series of calibration standards of Na_2SO_4 was prepared and analysed similarly. The sulphate ion concentration was determined by the equation:

$$SO_4^{2-}\ mg/L = \frac{1000\ X\ SO_4^{2-}}{Volume\ of\ water\ sample\ (ml)} \quad (3)$$

The chloride concentration of the water samples was determined by Mohr's Method. This was achieved by the titration of the water samples with standardized $AgNO_3$ solution using potassium chromate indicator. The turbidity of the water was determined with the aid of a turbidimeter (ORION Portable Turbidimeter, Thermo Scientific, USA), while its electrical conductivity was determined with a conductometer (Hanna

Primo 5, 1-1999 Pocket Conductivity Meter, USA).

Heavy and Trace Metals Determination

The heavy and trace metals present in the water samples were determined as follow: 5 mL concentrated HNO_3 was added to 50ml of the water samples, with continuous heating until the completion of the digestion process. The digested samples were washed with distilled water, filtered, and made up to 50 ml mark in a standard flask. Distilled water was used as blank and prepared in similar way. The metals Pb, Ca, Cu, Zn, Fe, Cd, Cr, Ni and Mg were determined with the aid of an Atomic Absorption Spectrophotometer AAS (Perkin-Elmer 305B) with the appropriate hollow cathode lamp for each metal determination. Na was determined with Flame Photometer (Flame Photometer, 115 VAC, Cole-Palmer, UK).

RESULTS AND DISCUSSION

Physicochemical Properties

The results of the physicochemical parameters of the water samples from the Lagos Centre and Ikorodu area are presented in Table 1. There was no significant difference in the pH of all the six water samples which ranged from 6.29 (Lagos Area Pipe Borne Water) to 6.90 (Lagos Area Well Water) (Table 1). The mean pH for Lagos central water samples was 6.62 ± 0.31, which was within the WHO, EU and NIS standards (6.5 8.5), while that of Ikorodu area water samples was 6.49 ± 0.18 which was slightly below the permissible limits (Table 2). This maybe an indication of the acidic nature of the groundwater in the area under study. pH less than 7 can impart taste to water or lead to corrosion of plumbing (Ano and Okwunodulu, 2008). This result is at par with others reported in literature (Ano and Okwunodulu, 2008; Oketola *et al.*, 2006; Olajire and Imeokpara, 2001). Okoye and Adeleke (1991) reported pH of 6.1 for underground waters in Akure in South-Western Nigeria. Ano and Okwunodulu (2008) obtained an average pH of 4.29 - 5.23 in their study of the groundwater of Aba and Umuahia in the Southeastern Nigeria. Reported pH range of underground water in Onitsha and environs (Southeastern Nigeria) was 4.8 - 5.1, while in the Benin area (Midwestern Nigeria), the pH was about 5.5 (Oketola *et al.*, 2006; Ogunkoya and Efi, 2003; Olajire and Imeokpara, 2001; Atuma and Ogbeide, 1984). The temperature of the water samples ranged from 26.8 to 27.0°C.

Table 1: Physicochemical Parameters of the Water Samples from Lagos Centre (LWW, LBW, & LTW) and Ikorodu area (KWW, KBW, & KSW)

PARAMETERS	LWW	LBW	LTW	KWW	KBW	KSW
pH	6.90 ± 0.10^{a}	6.67 ± 0.02^{b}	6.29 ± 0.02^{d}	6.35 ± 0.05^{d}	6.43 ± 0.01^{c}	6.70 ± 0.01^{b}
Temperature (°C)	26.80 ± 0.1^{c}	26.90 ± 0.10^{c}	27.00 ± 0.10^{c}	26.60 ± 0.3^{c}	27.60 ± 0.30^{b}	28.10 ± 0.21^{a}
Turbidity (NTU)	0.08 ± 0.05^{d}	0.10 ± 0.01^{c}	0.20 ± 0.03^{b}	1.00 ± 0.12^{a}	1.10 ± 0.14^{a}	0.10 ± 0.01^{c}
TS (mg/L)	250 ± 2.00^{c}	257 ± 2.29^{b}	263 ± 4.00^{a}	180 ± 2.00^{f}	205 ± 3.00^{e}	217 ± 5.20^{d}
TDS (mg/L)	169 ± 9.00^{b}	190 ± 5.00^{a}	164 ± 7.10^{b}	140 ± 11.00^{c}	164 ± 10.10^{b}	180 ± 11.80^{a}
TSS (mg/L)	81 ± 3.00^{b}	67 ± 2.00^{c}	99 ± 5.70^{a}	40 ± 2.10^{c}	41 ± 3.50^{d}	37 ± 3.90^{d}
DO (mgO_2/L)	4.01 ± 0.06^{b}	3.10 ± 0.30^{d}	$3.40\ \pm0.11^{c}$	$2.20\ \pm0.20^{e}$	4.24 ± 0.18^{a}	3.80 ± 0.25^{b}
BOD (mg O_2/L)	2.06 ± 0.09^{a}	1.01 ± 0.05^{c}	1.3 ± 0.12^{b}	1.91 ± 0.16^{a}	2.01 ± 0.11^{a}	1.40 ± 0.09^{b}
EC (µS/cm)	495 ± 11.00^{a}	342 ± 9.00^{c}	209 ± 7.00^{d}	399 ± 4.00^{b}	199.5 ± 5.50^{d}	399 ± 10.00^{b}
TH (mg/L)	44 ± 4.00^{a}	34 ± 3.00^{b}	22 ± 4.00^{c}	22 ± 1.00^{c}	18 ± 2.00^{d}	22 ± 3.00^{c}
Alkalinity (mg $CaCO_3$/L)	40 ± 5.00^{b}	60 ± 7.00^{a}	$30\ \pm3.00^{c}$	20 ± 2.00^{d}	10 ± 2.00^{e}	30 ± 4.10^{c}
Sulphates (mg/L)	10.89 ± 1.59^{c}	10.6 ± 1.10^{c}	20.10 ± 1.30^{a}	3.96 ± 0.13^{e}	7.84 ± 0.7^{d}	15.40 ± 0.99^{b}
CLRD (mg/L)	177.25 ± 3.9^{d}	191.43 ± 4.07^{c}	163.07 ± 2.95^{e}	233.97 ± 7.86^{b}	191.43 ± 0.03^{c}	297.78 ± 8.40^{a}
Nitrate (mg/L)	30.60 ± 1.22^{b}	26.1 ± 0.78^{c}	35.60 ± 2.51^{a}	11.60 ± 0.52^{d}	29.30 ± 3.10^{b}	26.70 ± 1.95^{c}
Acidity (mg $CaCO_3$/L)	100 ± 10.00^{a}	40 ± 3.00^{d}	40 ± 2.00^{c}	70 ± 4.00^{b}	100 ± 8.50^{a}	80 ± 6.00^{b}

Mean values of triplicate determinations ± standard error. Values in the same row with the same superscript are not significantly different. CLRD - chloride; TH - Total Hardness; EC - Electrical Conductivity.

Table 2: Mean values of the Physicochemical Properties of the Water Samples from Lagos Centre and Ikorodu area.

PARAMETERS (mg/L)	Lagos Centre mean values	Ikorodu area mean values	PERMISSIBLE LIMITS [a,b,c]
pH	6.62±0.31[a]	6.49±0.18[a]	6.5-8.5
TEMP (°C)	26.90.1[a]	27.40.76[b]	ambient
TURBIDITY (NTU)	0.13±0.06[a]	0.73±0.55[b]	5.0
TOTAL SOLIDS (mg/L)	256.7±6.5[b]	200.7±8.91[a]	1000
TOTAL DISSOLVED SOLIDS (mg/L)	174.3±1.38[a]	161.3±2.01[a]	500
TOTAL SUSPENDED SOLIDS (mg/L)	82.33±6.04[b]	39.33±2.08[a]	NA
DISSOLVED OXYGEN (mg/L)	3.50±0.46[a]	3.41±1.07[a]	5.0
BOD (mg/L)	1.46±0.54[a]	1.40±0.07[a]	NA
CONDUCTIVITY (μS/cm)	348.7±14.31[a]	332.5±11.52[a]	250
HARDNESS (mg CaCO3/L)	33.33±1.10[b]	20.67±2.31[a]	150
ALKALINITY (mg CaCO3/L)	43.33±5.28[b]	20.0±2.10[a]	100
CHLORIDE (mg/L)	177.25±4.18[a]	241.06±3.53[b]	250
SULPHATES (mg/L)	13.86±5.40[b]	9.07±5.82[a]	100
NITRATES (mg/L)	30.77±4.75[b]	22.53±3.56[a]	50
ACIDITY (mg CaCO3/L)	60.0±4.64[a]	83.33±5.28[b]	6.5

Mean values of triplicate determinations ± standard error. Values in the same row with the same superscript are not significantly different.

Table 3: World health Organisation (WHO), European Union (EU) and Nigerian Industrial Standards (NIS) Permissible Limits for Potable Water's Physicochemical Properties.

PARAMETERS (mg/L)	**WHO LIMITS[a]**	**EU LIMITS[b]**	**NIS LIMITS[c]**
pH	6.5-8.5	6.5-8.5	6.5-8.5
TEMP (°C)	ambient		
TURBIDITY (NTU)	5	NA	5
TOTAL SOLIDS(mg/L)	1000		
TOTAL DISSOLVED SOLIDS(mg/L)	20-1000	NA	500
TOTAL SUSPENDED SOLIDS(mg/L)	NA	NA	NA
DISSOLVED OXYGEN (mg O_2/L)	5	5	5
BOD (mg O_2/L)	NA	NA	NA
CONDUCTIVITY (μS/cm)	250	250	1000
T.HARDNESS (mg $CaCO_3$/L)	100-500	100-500	150
ALKALINITY(mg $CaCO_3$/L)	5-500	NA	100
CHLORIDE (mg/L)	250	250	250
SULPHATES (mg/L)	500	250	100
NITRATES (mg/L)	50	50	50
ACIDITY (mg $CaCO_3$/L)	6.5	NA	NA

NA = Not Available

[a] WHO (2010, 2006)

[b] European Union (2010)

[c] NIS (2007)

The conductivity measurement data obtained for this study ranged between 199.5 S/cm for KBW (Ikorodu boreholes) to 495 S/cm for LWW (Lagos wells), with an average value of 348.67 S/cm for the entire Lagos samples and an average value of 332.5 S/m for the entire Ikorodu samples. The maximum permissible standards for conductivity of drinking water are 250 S/cm (WHO and EU) and 1000 S/cm by NIS (Table 3). Values exceeding 1000 S/cm limit is indicative of saline intrusions into the groundwater (Adewuyi *et al.,* 2010). All the water samples (except LTW - Lagos Centre Pipe Borne Water; KBW - Ikorodu Borehole Water) have higher turbidity values, which is indicative of the presence of ionic contaminant. This is due to the continuous discharge of chemicals and salts used in the industries, and leachates from the dumpsites which might have percolated into the groundwater. Ikorodu borehole water also recorded high conductivity value presumably due to an enriching effect from inland run-off which might contain some dissolved ions (Egereonu and Odumegwu, 2006).

The total solids concentration in the water samples were within the permissible limit of 1000 mg/L. The values of the total solids ranged from 180mg/L (KWW - Ikorodu Well Water) to 263mg/L (LTW - Lagos Centre Pipe Borne Water). The main sources of solids in natural waters are rain waters, wind erosion of soil surfaces, solids emanating from domestic wastes, run-off from roads and dumpsites as well as industrial wastes. Solids in water are undesirable for many reasons; they degrade the quality of drinking water and they also reduce the utility of water for irrigation and industrial purposes.

The Total Suspended Solids (TSS) value ranged from 37.0 mg/L (KSW) to 99.0 mg/L (LTW) (Table 1), with an average value of 82.33 mg/L for Lagos drinking water sources and 39.33 mg/L for Ikorodu drinking water sources. The turbidity values obtained from all the drinking water sources in Lagos are higher than those obtained for Ikorodu, indicating a higher pollution in Lagos.

Total Dissolved Solids (TDS) which is the portion of total solids that passes through a filter and remain after evaporation and drying to constant weight at 180^0C, is a measure of the amount of materials (solute) dissolved in water (Adejuwon and Mbuk, 2011). The TDS values obtained for all the samples ranged from 140 mg/L (KWW Ikorodu well water) to 190 mg/L (LBW Lagos Centre borehole water), with a mean of 174.3mg/L for the Lagos Centre sample and mean of 161.3mg/L for *Ikorodu water* sample (Table 2). These values are within the 500mg/L maximum permissible limit set by NIS and WHO for drinking water (Table 3). The higher mean TDS value observed in Lagos Centre water samples could also be linked to the higher level of industrialization and population density. The KSW (Ikorodu stream water) which had a high mean value of 180mg/L (TDS) could be as a result direct discharge of chemicals, domestic waste waters, run-off from roads and dumpsites etc which get finally washed into the natural water. The materials that determines the amount of TDS include, carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, organic ions and other ions. In this study, the possible cause of low amount of TDS was the minimal presence of these chemicals in the groundwater, while places with higher TDS value was due to high presence of the chemicals in the water sources (Adejuwon and Mbuk, 2011). The high content of dissolved solids increases the density of water and influences osmoregulation of fresh water organism. They reduce solubility of gases (like oxygen) and utility of water for drinking, irrigational, and industrial purposes (Gupta, 2001). TDS in excess quantity is responsible for the wide spread of gastric human system, produce undesirable taste, gastro intestinal irritation and corrosion (Pragathiswaran *et al.,* 2008).

The dissolved oxygen (DO) values for the entire sample analysed ranged from 2.20 mg/L (Ikorodu Well Water) to 4.24 mg/L (Ikorodu Borehole Water) (Table 1) with a mean value of 3.50 mg/L for Lagos Centre samples and 3.41 mg/L for Ikorodu area sample (Table 2). These values are within the permissible limits of 5 mg/L set by WHO and EU (Table 3). The Biochemical Oxygen Demand (BOD) values range from 1.01 mgO_2/L (Lagos Borehole Water) to 2.06 mgO_2/L (Lagos Well Water), with an average of 1.46 mgO_2/L for Lagos Centre water body, and 1.77 mgO_2/L for Ikorodu area water. BOD test is used to determine the pollution strength of water, waste water and quality of the receiving surface water. According to classification of surface water quality, BOD values above 2.0 mgO_2/L is indicative of pollution, while those above 3.0 mgO_2/L are regarded as highly polluted and unfit for human consumption. Consequently, the Lagos well water and Ikorodu borehole water may be regarded as unfit for human consumption based on their BOD values alone.

The mean total hardness for the Lagos Centre water samples was 33.33 $mgCaCO_3$/L, while for Ikorodu water samples the mean value was 20.67 $mgCaCO_3$/L (Table 1). These values are far below the permissible limit, since water body with total hardness below 100mg/L is considered safe by WHO, EU and NIS (Table 3). The total hardness of water is a measure of the total contributions from alkaline earth ions like Ca and Mg, and other polyvalent cations e.g. Fe, Zn, Mn, Al, and Sr (Adewuyi et al., 2010).

The alkalinity values ranged from 10.0 to 44.0 mg/L, with Ikorodu borehole water having the lowest value (10.0 $mgCaCO_3$/L), while Lagos well water had the highest alkalinity. These values are below the permissible limit of 100mg/L for water (NIS). Alkalinity leads to corrosion and influences chemical and biochemical reactions (George *et al.*, 2010). The acidity for both Lagos Centre and Ikorodu area water also ranged from 40 to 100 mg/L. However, the maximum permissible level of acidity in drinking water is 6.5 $mgCaCO_3$/L for drinking water (Egereonu and Odumegwu, 2006). All the water analysed exceeded the WHO limits and are therefore unsuitable for drinking purposes. Total acidity is usually derived from inorganic and organic acidifying precursors including SO_x and NO_x in most industrialized regions, due to the prevailing industrial processes, which involves gaseous and particulate emissions, organic waste decomposing under partially reducing conditions into organic acids as well as acidic precipitation (Ogunkoya and Efi, 2003) The effects of acidic precipitation include the inhibition of microbial decomposition, nitrogen fixation and increased solubility and mobility of toxic heavy metals within the environment (McDowell, 1988).

The chloride concentrations ranged from 163.07 mg/L (Lagos pipe borne water) to 297.78 mg/L (Ikorodu stream water). The mean value of the Lagos Centre water was 177.25 mg/L which was below the mean value for the Ikorodu area water sources of 241.06 mg/L (Table 2). The permissible limit for chloride in potable water is 250 mg/L, according to WHO, EU and NIS (Table 3). Most of the water samples from different sources were within the chloride limit with the exception of Ikorodu stream waters (297.78 mg/L). The high chloride concentration in the Ikorodu stream water may be due in parts to the discharged of chloride bearing effluent into the stream by the industries, ingress of saline water from backwater, and presence of soluble chloride salt bearing rock (Geetha *et al.,* 2008; George *et al.*, 2010). The appreciable lower chloride content obtained in LTW could be as a result of municipal treatment of pipe borne water in Lagos. According to Adewuyi *et al.* (2010), chloride is not considered harmful to humans, but imparts a salty taste to water above the permissible limit.

The concentration of sulphates ranged from 3.96 mg/L to 20.1 mg/L for Ikorodu area well water and Lagos Centre pipe borne water respectively. The mean value obtained for the Lagos Centre water was 13.86 mg/L and that of the Ikorodu area 9.07 mg/L. This value is far below the maximum permissible limit of sulphate in water (Table 3).

The concentrations of nitrates ranged from 11.60 mg/L to 35.60 mg/L for the water samples and are within the permissible limit for nitrate. The permissible standard stated by WHO, EU and NIS for nitrates in potable water is 50 mg/L. The nitrate concentration in the Lagos Centre water samples was significantly higher than that of the Ikorodu area water samples. High concentration of nitrate in drinking water is debilitating on human health. Nitrate is a strong oxidizing agent and NO_2 can react with secondary amines present in human body, to form nitrosamines (George *et al.,* 2010). The major adverse effect associated with human exposure to nitrate is methaemoglobinema. Nitrate converts haemoglobin to methaemoglobin by oxidizing the Fe^{2+} in haemoglobin to Fe^{3+} which cannot transport oxygen. High level of Fe^{3+}-haemoglobin in human blood can cause cyanosis, characterized by bluish skin and lips (Al-Dabbagh *et al.,* 1986).

Trace and Heavy Metals

Lead is one of the poisonous trace elements often found in polluted natural waters. The Pb concentration ranged from 0.098 mg/L (Lagos Pipe Borne Water) to 0.140 mg/L (Ikorodu Borehole Water) (Table 4), with an average value of 0.112 mg/L for Lagos Centre water samples and 0.113 mg/L for Ikorodu area water samples (Table 4). The permissible standard limit for lead in potable water is 0.01 mg/L according to WHO, EU and NIS (Table 5). All the water samples (both Lagos Centre and Ikorodu area) exceeded the permissible limits. Also, Pb concentrations in the Lagos Centre were significantly higher than that of the Ikorodu area samples. Consequently, the water is not suitable for drinking purpose without treatments based on the high Pb concentration. Pb probably percolates into the water body through municipal wastes, mining activities, plumbing, paint residue, burning of coal and leaded gasoline, etc. High Pb concentration in human may lead to anaemia, kidney diseases, cancer, interferes with vitamin D metabolism, affect mental development in infants, and toxic to the central and peripheral nervous systems (NIS, 2007; Egereonu and Osuzu, 2005). Cadmium, another trace element of serious environmental concern was not detected in the water samples.

Copper concentrations in the water samples ranged from 0.027 mg/L (LWW and KWW) to 0.064 mg/L (LBW) (Table 4), and there was no significant difference in the mean values of the Lagos Centre water samples and Ikorodu water samples (Table 4). The Cu concentrations in all the water samples was below the permissible limits of 1.0 2.0 mg/L set by WHO, EU and NIS, concentrations above the permissible limits can cause gastro intestinal disorder.

Table 4: Metals Concentrations of the Water Samples from Lagos Centre (LWW, LBW, & LTW) and Ikorodu area (KWW, KBW, & KSW).

METALS (mg/L)	LWW	LBW	LTW	KWW	KBW	KSW	Mean - Lagos area (mg/L)	Mean - Ikorodu area (mg/L)	Permisible limits (mg/L)[1]
Pb	0.116 ± 0.030^{b}	0.121 ± 0.015^{d}	0.099 ± 0.006^{a}	0.098 ± 0.005^{a}	0.140 ± 0.012^{d}	0.102 ± 0.001^{c}	0.111 ± 0.011	0.113 ± 0.013	0..0201
Cd	ND	ND	ND	ND	ND ND	-	-	0.003	
Cu	0.027 ± 0.004^{a}	0.064 ± 0.002^{d}	0.047 ± 0.003^{b}	0.027 ± 0.003^{a}	0.051 ± 0.002^{c}	0.060 ± 0.007^{c}	0.046 ± 0.019	0.046 ± 0.017	2.0
Fe	0.151 ± 0.021^{c}	0.171 ± 0.019^{d}	0.139 ± 0.013^{b}	0.096 ± 0.008^{a}	1.804 ± 0.420^{d}	0.146 ± 0.031^{c}	0.154 ± 0.016	0.682 ± 0.97	0.3
Cr	0.026 ± 0.003^{b}	0.021 ± 0.004^{b}	0.009 ± 0.0002^{a}	0.01 ± 0.0001^{a}	0.011 ± 0.001^{a}	0.016 ± 0.004^{a}	0.0187 ± 0.09	0.012 ± 0.003	0.05
Zn	0.311 ± 0.020^{c}	0.111 ± 0.010^{a}	0.410 ± 0.0250^{d}	0.213 ± 0.015^{b}	0.328 ± 0.039^{c}	0.270 ± 0.050^{b}	0.277 ± 0.152	0.270 ± 0.003	3.0
Na	42.000 ± 0.520^{c}	46.000 ± 0.390^{d}	68.000 ± 0.480^{f}	16.000 ± 0.300^{a}	49.000 ± 0.700^{e}	24.000 ± 0.400^{b}	$52/00\pm14.00$	29.90 ± 17.00	200
Ni	0.721 ± 0.0410^{a}	0.814 ± 0.038^{b}	0.951 ± 0.066^{c}	0.953 ± 0.068^{c}	0.814 ± 0.025^{b}	1.021 ± 0.130^{d}	0.829 ± 0.116	0.929 ± 0.106	0.02
Mg	6.410 ± 0.420^{c}	4.950 ± 0.350^{b}	7.490 ± 0.610^{d}	7.490 ± 0.700^{d}	2.620 ± 0.200^{a}	7.490 ± 0.330^{d}	6.283 ± 1.275	5.867 ± 2.812	0.2
Ca	17.600 ± 1.310^{d}	13.600 ± 1.200^{c}	8.820 ± 0.610^{b}	8.820 ± 0.490^{b}	7.200 ± 0.440^{a}	8.820 ± 0.310^{b}	13.34 ± 4.40	8.280 ± 0.94	75

[1]NIS Nigeria Industrial Standards
Mean values of triplicate determinations ± standard error. Values in the same row with the same superscript are not significantly different.

The iron concentrations ranged from 0.096 mg/L (LTW) to 1.804 mg/L (KBW) (Table 4), while the mean concentration value for the Lagos Centre and Ikorodu area was 0.54 mg/L and 0.682 mg/L respectively (Table 4). All except KBW had Fe concentration below the maximum permissible limit set by WHO, EU and NIS (Table 5). Although Fe has no serious health implications (NIS, 2007), the high Fe concentration (1.804 mg/L) observed in the Ikorodu area borehole water samples may be attributed to the soil composition of the area where the boreholes were sited (Amadi and Morrison, 2001).

Calcium concentrations varied from 7.20mg/L (Ikorodu borehole water) to 17.60mg/L (Lagos wells) (Table 4), with a mean concentration of 13.34 mg/L and 8.82 mg/L for Lagos Centre and Ikorodu area water samples. The Ca concentration of the Lagos Centre water samples was significantly higher than that of the Ikorodu area. The concentrations obtained for all the water samples were lower than the maximum permissible limit (75 mg/L) as set by WHO, EU, and NIS, hence the water is suitable for human consumption and industrial use with respect to Ca.

The concentrations of Mg varied from 2.62 mg/L (KBW) to 7.49 mg/L for (LTW, KWW, and KBW) (Table 4), with a mean concentration value of 6.28

Table 5: WHO, EU and NIS (Nigerian Industrial Standards) for Drinking Water (Trace Metal Concentrations).

Metal concentration (mg/L)	WHO limits (mg/L)	EU limits (mg/L)	NIS Limits (mg/L)
Pb	0.01	0.01	0.01
Cd	0.003	0.005	0.003
Cu	2	2	1
Fe	0.3	0.2	0.3
Cr	0.05	0.05	0.05
Zn	3	NA	3
Na	200	200	200
Ni	0.02	0.02	0.02
Mg	20-125	20-125	0.2
Ca	75	NA	NA

and 5.86 mg/L for the Lagos Centre and Ikorodu area water samples. The Mg concentration for all the water samples is above the 0.2 mg/L maximum permissible limit as set by NIS. Actually, Mg is a beneficial metal, but toxic at high concentrations and can cause water hardness, and also exert a cathartic and diuretic action (APHA, 1985). Mg is not uniformly distributed in water and it is also influenced by human activities on the environment (Ishaya and Abaje, 2009 a, b).

Chromium concentrations ranged from 0.009 mg/L (Ikorodu stream) to 0.026 mg/L (Lagos well water) with mean value of 0.0187 mg/L and 0.012 mg/L for Lagos Centre and Ikorodu area water samples. The Cr concentrations for all the water samples was below the maximum permissible limit set by WHO, EU and NIS (Table 5). However, the Cr concentrations in Lagos Centre was significantly higher than that of the Ikorodu areas, and this may be as a result of the industrial activities which led to increase in the Cr level in the environment. Ingestion of water with Cr concentration above 0.05 mg/L can lead to cancer or allergic dermatitis (NIS, 2007).

Zinc concentrations ranged from 0.111 mg/L (Lagos borehole water) to 0.410mg/L (Lagos pipe borne water) (Table 4). The mean concentration values for the Lagos Centre and Ikorodu area was 0.277 and 0.058 mg/L respectively. The maximum permissible limit as set by WHO and NIS for Zn concentration is 0.3 mg/L. The Zn concentration of most water samples was below the maximum permissible limit, however, LWW, LTW, and KBW was above the limit. Although zinc is not a human carcinogen, but excessive intake of zinc through contaminated food chain could lead to vomiting, dehydration, abdominal pain, lethargy and dizziness (ATSDR, 1994).

The concentration of sodium ranged from 16.00 mg/L (Ikorodu well water) to 68.00 mg/L (Lagos Pipe Borne Water) (Table 4) with the mean concentration value of 52.0 mg/L and 30.00 mg/L for Lagos Centre and Ikorodu area water samples (Table 4). Also, the mean Na concentration in the industrialised Lagos Centre was significantly higher than that in Ikorodu area. The permissible Na concentration for potable water is 200 mg/L as set by WHO, EU and NIS (Table 5). The concentrations of Na were therefore within the acceptable limits for all the samples. Excess Na concentration in any water sample could be linked to saline water intrusions, discharge of domestic and Industrial effluents on to the ground or water bodies (George *et al.*, 2010).

Nickel concentrations ranged from 0.721 mg/L (Lagos well water) to 1.021 mg/L (Ikorodu stream) (Table 4), with a mean concentration value of 0.829 mg/L and 0.929 mg/L for Lagos Centre and Ikorodu area (Table 4). The WHO, EU and NIS permissible limit of Ni concentration in potable water is 0.02 mg/L and all the water samples exceeded the limit. Also, the concentration of Ni in the Ikorodu water samples was significantly higher than that of the Lagos Centre with KSW having abnormally high mean concentration of 1.021 mg/L. Historical data reveals that the forest in the vicinity of the 'Etunrenren' stream was an abandoned dumpsites which had existed for decades before the afforestation, hence the high Ni concentration in the nearby stream may be the resultant effect of leachates that percolates into the water body. Ni has low toxicity comparable to Zn, Mn, and Cr; and does not accumulate in the tissues.

CONCLUSION

The physicochemical and metal analysis of the water samples from the urban, densely populated and industrialised Lagos metropolis (Lagos Centre) and the off-town less urbanised and less industrialised part of Lagos (Ikorodu area), showed that the water quality from the two areas is poor for drinking. The level of industrialization, population density, and location of dumpsites impacted more on the drinking water in Lagos Centre than in Ikorodu area. The higher concentrations of the total solids, total dissolved solids, total suspended solids, dissolved oxygen, total hardness, nitrate, etc., in the Lagos Centre water samples compared to the Ikorodu area samples, is a reflection of the influence of industrialization, urbanization, population density, etc., on the environment. The quality of the water samples could however be improved by treatment before drinking, and also by reducing the industrial pollution of the environment. The surface water at Ikorodu 'Etunrenren' stream is not safe for drinking not just due to the unhygienic environment where it is sourced, but also because most of its physicochemical properties and heavy and trace metal contents are above the maximum permissible levels for drinking.

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