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Drinking water quality and human health risk evaluations in rural and urban areas of Ibeju-Lekki and Epe local government areas, Lagos, Nigeria

Temitope O. Sogbanmu[a], Sherifat O. Aitsegame[a], Olubunmi A. Otubanjo[b], and John O. Odiyo[c]

[a]Ecotoxicology and Conservation Unit, Department of Zoology, Faculty of Science, University of Lagos, Lagos, Nigeria; [b]Parasitology and Bioinformatics Unit, Department of Zoology, Faculty of Science, University of Lagos, Lagos, Nigeria; [c]Department of Hydrology and Water Resources, University of Venda, Thohoyandu, South Africa

ABSTRACT

This study evaluated the drinking water quality and associated human health risks in three (3) rural and urban areas each in Ibeju-Lekki and Epe local government areas of Lagos, Nigeria. Two hundred structured questionnaires were administered to stakeholders, and samples were obtained from prevailing drinking water sources in the study areas using standard methods for microbiological, physicochemical, heavy metals and human health risk evaluations. Wells and boreholes were the major sources of drinking water in the rural and urban areas, respectively. Drinking water samples from the study areas contained more than one pathogenic bacterium. The physicochemical parameters except total organic carbon (TOC) were within permissible limits of the Nigerian Standard for Drinking Water Quality (NSDWQ). The mean values of Cd and As exceeded the maximum permissible limit of NSDWQ. The hazard quotient of cadmium and arsenic was greater than 1 indicating potential health risks if the water is not treated. In order to achieve the UN Sustainable Development Goal 6 on clean water and sanitation by the next decade (2030), we recommend that frequent monitoring, treatment and stakeholders education on drinking water treatment techniques should be actively conducted particularly in rural areas in the state, country, region and continent.

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Introduction

The provision and access to water supply is one of the fundamental needs for human survival. Access to water supply implies having sufficient water for personal and domestic uses of at least 50–100 L of water per person per day from a safe source that is acceptable, affordable and physically accessible (UN 2012). According to the FAO (2007), water-related diseases have been interfering with basic human development in African countries particularly Nigeria. The common sources of water that are available to local communities in Nigeria are severely affected by a number of anthropogenic

CONTACT Temitope O. Sogbanmu tsogbanmu@unilag.edu.ng Ecotoxicology and Conservation Unit, Department of Zoology, Faculty of Science, University of Lagos, Akoka, Lagos, 101017, Nigeria.

factors of which pollution remains the most dominant. Water may be polluted in various ways. The three main forms of water pollution are physical, bacterial and chemical (Fall *et al.* 2007). The presence of pathogens in drinking water causing diarrhea, cholera and other diseases is mainly due to fecal contamination.

Naturally occurring substances in groundwater can also have adverse health impacts without any detectable taste or odor. These are generally inorganic substances derived from geologic materials and are referred to as geogenic contaminants. One of the most important geogenic contaminants is arsenic (McArthur *et al.* 2001). Excessive intake of these substances from contaminated drinking water can lead to cancer, dental and skeletal fluorosis, acute nausea, memory lapses, renal failure, anemia, stunted growth, fetal abnormalities and skin rashes (Hunter *et al.* 2010). Human health risk assessment is the characterization of the potential adverse health effects to humans as a result of exposures to environmental hazards (USEPA 2012).

The global response to the problem of sustainable access to safe drinking water and basic sanitation culminated in the inclusion of specific water-related targets in the Sustainable Development Goals (SDGs) number six (6) which replaced the Millennium Development Goals (MDGs) that ended in 2015. The goal is to ensure availability and sustainable management of water and sanitation for all by 2030 (WHO and UNICEF 2017). Achieving universal access to basic sanitation and ending the unsafe practice of open defecation will require substantial acceleration of progress in rural areas of Central and Southern Asia, Eastern and South-Eastern Asia and Sub-Saharan Africa (SSA). SSA alone accounts for more than 40% of the global population without access to improved drinking water. Sixty-six (66) million people in Nigeria do not have improved drinking water sources, third after China (119 million) and India (97 million) (UNICEF and WHO 2012).

Along with many SSA countries including Ghana, Rwanda, Botswana and Sierra Leone, Nigeria ranks behind in access to potable water supply (Marks *et al.* 2013). The lack of access to water and sanitation is debilitating. The major concerns are health and socioeconomic impacts of the microbial, physicochemical and heavy metals parameters in the water on the end users and the environment (Nyanganji *et al.* 2011). There is a paucity of data on these parameters and their continuous assessment in developing countries such as Nigeria (Adeoye *et al.* 2013). Thus, the aim of this study was to assess the drinking water quality and human health risks in Ibeju-Lekki and Epe local government areas of Lagos State, Nigeria. This will provide evidence-based data to inform targeted interventions by the regulatory agencies and policy-makers.

Materials and methods

Study area

The study was conducted in Ibeju-Lekki and Epe local government areas of Lagos state, Nigeria (Figure 1). Ibeju-Lekki and Epe local government areas have a total population of 117,793 and 181,409, respectively (National Bureau of Statistics 2007; Omenai and Ayodele 2014). Ibeju-Lekki local government area is approximately 75 km in length and 20 km at its widest point (Omenai and Ayodele 2014), while Epe local government area has a total land area of 121 km^2 (Olujide 2008). The communities selected for this study

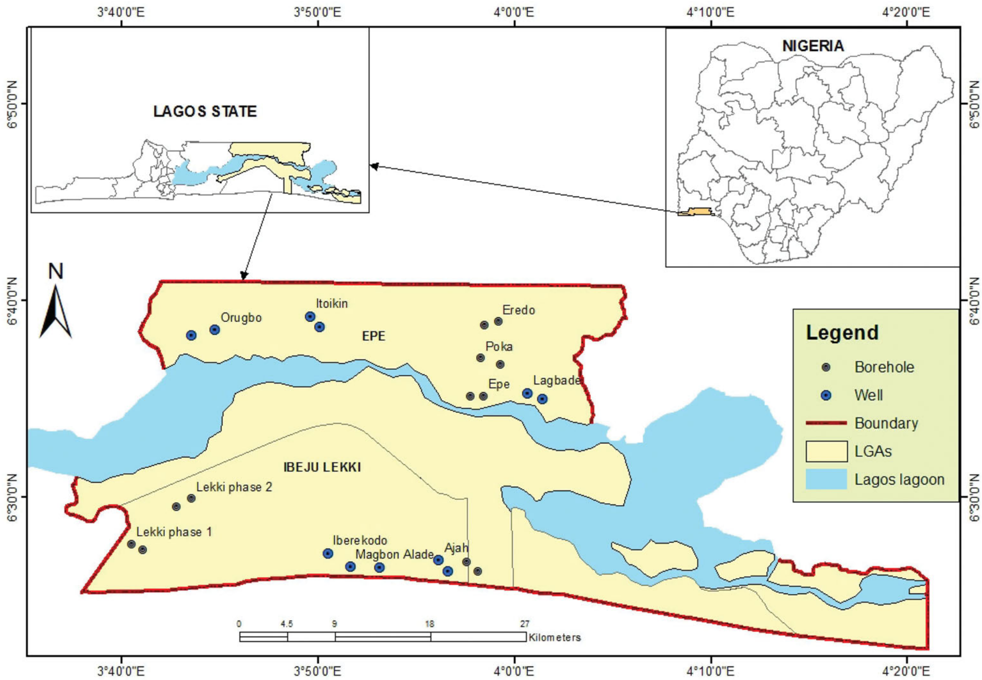

Figure 1. Map of study area showing sampling locations in Ibeju-Lekki and Epe local government areas of Lagos state, Nigeria.

were Magbon-Alade, Ajah, Iberekodo (rural areas), Lekki Phase 1, Lekki Phase 2 and Ajah (urban areas) in Ibeju-lekki local government area, and Lagbade, Orugbo, Itoikin (rural areas), Poka, Eredo and Epe (urban areas) in Epe local government area (Figure 1). The justification for the selection of these settlements was based on their distinct geographical characteristics and the level of physical development in the area (Balogun *et al.* 1999).

Questionnaire administration

One hundred (100) structured questionnaires were administered to consenting household members in each local government area totaling two hundred (200) questionnaires in all. The information obtained centered around access to water supply in the communities, sources of water supply, the nature and availability of the sources, water treatment methods and the mode of household wastes disposal.

Sample collection

Standard methods described by the American Public Health Association (APHA 1998) were used for the collection of water samples. A total of 24 water samples were collected from 12 locations within the study area in the month of October, 2017 and analyzed for microbial, physicochemical and heavy metals parameters.

Microbiological evaluations

Presumptive tests to evaluate the presence of coliforms in the water samples were conducted using the multiple tube fermentation technique/most probable number (MPN) method as described by Mackie and McCartney (1989). Presumptive coliforms count was obtained by making a reference to the MacCrady's probability table. MPN of coliforms per 100 mL of water sample was computed from combinations of positive and negative results obtained from the test tubes. Confirmatory tests were carried out to ascertain the presence and types of coliform bacteria present in the water samples. Isolates were identified by a combination of colonial and morphological characterization on solid media together with standard biochemical reactions as described by Cowan and Steel (1993). The standard plate count was used for the enumeration, isolation and identification of aerobic heterotrophic bacteria present in the water sample. The obtained isolates were characterized and identified using the schemes by Holt *et al.* (1994).

Physicochemical evaluations

Physicochemical parameters were evaluated in the water sample including pH, turbidity, electrical conductivity (EC), total organic carbon (TOC), total dissolved solids (TDS), nitrate, sulfate, ammonia and chloride. Turbidity was determined by nephelometry, TDS was determined by gravimetric method, chloride was determined by argentometric titration, sulfate was determined by titrimetry and nitrate was determined by colorimetric method. pH and conductivity were determined using Hanna Multi Meter (Hanna instruments, Romania). The heavy metals analyzed were iron (Fe), manganese (Mn), cadmium (Cd), chromium (Cr), cobalt (Co), arsenic (As) and lead (Pb). The extraction of heavy metals in the water samples was by digestion with a mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) according to Odey *et al.* (2018). The concentrations of heavy metals in the water samples were determined with Micro Plasma Atomic Emission Spectrometer (MP-AES).

Data analysis

Statistical analysis

Statistical analysis was carried out using independent sample *t*-test to determine significant differences in the mean values of physicochemical parameters. Significant differences were set at $p<.05$. The mean of the parameters was compared with relevant international, and national standards and appropriate deductions were made (NSDWQ 2007; WHO 2011).

Human health risk evaluations

Health risks associated with ingestion of heavy metals in the water samples from the study area were assessed using the chronic daily intake (CDI) and hazard index parameters. The CDI through water ingestion was calculated as follows; $CDI = C \times DI/BW$

(USEPA 2005) where C – represents the concentration of heavy metals in water (μg/L), DI – represents average daily intake rate (2 L/day), BW – represents body weight (72 kg) (Belkhiri *et al.* 2017). The hazard quotient (HQ) for non-carcinogenic risk was calculated as follows: HQ = CDI/RfD (Gerba 2001). The hazard index was calculated as the sum of the HQs of each contaminant (heavy metals in this case): Hazard Index (HI)=HQ + HQ + HQ+ … (Kumar and Kumar 2018).

Results

Questionnaire responses

Most respondents in the study areas were males particularly in the rural areas. The age range of highest proportion (27%) was between 30 and 39 y. The level of education of most respondents in the rural and urban areas was primary and tertiary education, respectively. The source of livelihood of the highest proportion of respondents in the rural areas was fishing, while the highest in the urban areas was trading/civil service (Table 1). The dominant sources of drinking water were wells and boreholes in the rural and urban areas, respectively. Most respondents in the rural and urban areas do not engage in any form of water treatment with only a low percentage of some form of water treatment in the Ibeju-Lekki Urban area (Table 1). The major method of solid waste disposal in the rural areas is by burning, while in the urban areas, most respondents engage the services of government approved waste collectors (Lagos Waste Management Authority – LAWMA). Domestic wastewater is principally channeled into the streets in the rural areas, while drainages are utilized by most respondents in the urban areas (Table 1).

Microbiological quality of drinking water from Ibeju-Lekki and Epe local government areas, Lagos

The test for microbiological quality of drinking water in the study areas showed that 15 out of the 24 samples were indicative of the presence of coliforms. These samples were subjected to confirmatory tests and five tested positive for the presence of fecal coliforms. From the confirmatory and completed tests carried out on the tubes with positive results, a total of 61 bacterial isolates were obtained (Table 2). All the water samples from the study areas contained more than one species of bacteria pathogen. A total of 20 (32.8%) of the 61 bacteria isolates were obtained from rural communities in Ibeju-Lekki and 13 (21.3%) were isolated from the urban communities in Ibeju-Lekki, while 16 (26.2%) and 12 (19.7%) were isolated from rural and urban communities of Epe local government areas, respectively (Table 2).

Staphylococcus aureus, Micrococcus luteus, Pseudomonas aeruginosa and *Escherichia coli* had the highest occurrence in Ibeju-Lekki rural communities, while *Enterobacter aerogenes* and *P. aeruginosa* were the most frequently encountered in water samples collected from Ibeju-Lekki urban communities. In Epe local government area, *M. luteus* and *E. aerogenes* had the highest occurrence in samples obtained from rural communities, while *S. aureus, P. aeruginosa* and *E. aerogenes* were the most encountered bacteria

Table 1. Sociodemographic characteristics of households, sources, treatment of drinking water and wastes disposal methods in the study area.

	Socio-demographics		Ibeju-Lekki Epe		
	Rural	Urban	Rural	Urban	Total (%)
Sex					
Male	30	26	25	21	102(51%)
Female	20	24	25	29	98 (49%)
Age range (years)					
18–20	12	11	7	12	42 (21%)
30–39	13	12	15	14	54 (27%)
40–49	12	16	13	11	52 (26%)
50 and above	12	10	12	12	46 (23%)
No response	1	1	3	1	6 (3%)
Education					
Primary	22	8	18	8	56 (28%)
Secondary	16	10	14	12	52 (26%)
Tertiary	6	32	5	29	72 (36%)
Others	3	0	10	0	13 (6.5%)
None	3	0	3	1	7 (3.5%)
Occupation					
Fishing	34	0	30	0	64 (32%)
Farming	11	1	12	2	26 (13%)
Trading/business	3	20	5	22	50 (25%)
Civil servant	1	21	1	17	40 (20%)
Student	1	7	1	8	17 (8.5%)
Unemployed	0	1	1	1	3 (1.5%)

Water sources, treatment and wastewater disposal	Ibeju-Lekki		Epe		
	Rural	Urban	Rural	Urban	Total (%)
Source of drinking water					
Borehole	4	34	2	42	82 (41%)
Well	42	3	40	3	88 (44%)
Stream	4	0	8	0	12 (6%)
Water Tanker	0	12	0	0	12 (6%)
Tap	0	1	0	5	6 (3%)
Drinking water treatment method					
Filtration	1	11	4	6	22 (11%)
Boiling	0	10	1	4	15 (7.5%)
Chemical treatment	1	16	0	8	25 (12.5%)
Coagulation/ Flocculation	7	6	3	2	18 (9%)
None	41	7	42	30	120 (60%)
Solid wastes disposal methods					
LAWMA	4	32	5	26	67 (33.5%)
LWDV	1	12	1	9	23 (11.5%)
BWNB	45	6	44	15	110 (55%)
Domestic wastewater disposal methods					
Into drainage channels	7	38	5	33	83 (41.5%)
Directly into the street	43	9	45	15	112 (56%)
Into septic tanks	0	3	0	2	5 (2.5%)

Key: LAWMA – Lagos State Waste Management Agency, LWDV – Local waste disposal vendors, BWNB – Burning of wastes in nearby bushes around the house.

in water samples obtained from urban communities (Table 2). It was also observed from the results that fecal coliforms, *E. coli*, *Salmonella typhi*, *Shigella dysenteriae*, *Klebsiella oxytoca* and *Alicaligenes faecalis* were only isolated from well water samples collected from rural communities and none was isolated from samples collected from urban communities in both local government areas (SM 1).

Table 2. Bacterial analyses of drinking water samples in the study areas.

Local Government Area	Habitat Type	Community	Source of Water	MPN per 100 mL	Standard plate count (cfu/mL)
Ibeju-lekki	Rural	Iberekodo	Well	9.2	11.4×10^6
		Magbon Alade	Well	150	21.2×10^6
		Ajah	Well	93	10.6×10^6
	Urban	Ajah	Borehole	23	12.8×10^6
		Lekki Phase 1	Borehole	9.2	12.2×10^6
		Lekki Phase 2	Borehole	< 3.0	5.8×10^6
Epe	Rural	Lagbade	Well	7.4	14.2×10^6
		Itoikin	Well	38	19.0×10^6
		Orugbo	Well	9.2	11.8×10^6
	Urban	Epe	Borehole	3.6	10.6×10^6
		Poka	Borehole	< 3.0	8.0×10^6
		Eredo	Borehole	< 3.0	8.6×10^6

	Ibeju-Lekki		Epe			
Bacterial Isolates	Rural	Urban	Rural	Urban	Total	Percentage (%)
Shigella dysenteriae	1	0	0	0	1	1.6
Staphylococcus aureus	3	2	1	3	9	14.8
Micrococcus luteus	3	2	3	2	10	16.4
Pseudomonas aeruginosa	3	3	2	3	11	18
Bacillus cereus	2	2	1	1	6	9.8
Enterobacter aerogenes	1	3	3	3	10	16.4
Salmonella typhi	2	0	0	0	2	3.3
Klebsiella oxytoca	1	0	1	0	2	3.3
Bacillus alvei	0	0	1	0	1	1.6
Bacillus megaterium	0	1	1	0	2	3.3
Alicaligenes faecalis	1	0	1	0	2	3.3
Escherichia coli	3	0	2	0	5	8.2
Total	20	13	16	12	61	100

Physicochemical parameters of drinking water from Ibeju-Lekki and Epe local government areas, Lagos

The physicochemical characteristics of the water samples from the study areas are presented in Table 3. pH ranged from neutral to alkaline with values range from 7.4 ± 0.4 (Epe urban) to 9.56 ± 0.7 (Ibeju-Lekki rural). The color of the water samples had values ranging from 6.0 ± 4.8 Pt/Co (Epe urban) to 10.1 ± 2.7 Pt/Co (Epe rural). The mean EC ranged from 107.7 ± 126.4 µS/cm (Epe urban) to 434.7 ± 106.2 µS/cm (Ibeju-Lekki rural). TDS levels varied from 55.7 ± 62.8 mg/L (Epe urban) to 218.3 ± 54.6 mg/L (Ibeju-Lekki rural). Turbidity ranged from 1.5 ± 0 NTU (Ibeju-Lekki urban) to 2.7 ± 0.3 NTU (Epe urban). Sulfates ranged from a mean value of 6.1 ± 6.4 mg/L (Epe urban) to 20.7 ± 7.7 mg/L (Ibeju-Lekki rural). The mean nitrate values varied from 7.5 ± 8.2 mg/L (Epe urban) to 19.1 ± 8.1 mg/L (Ibeju-Lekki rural).

TOC ranged from 17.3 ± 7.4 mg/L (Epe rural) to 23.0 ± 5.6 mg/L (Epe urban). The mean value of chloride ranged from 51.5 ± 8.7 mg/L (Ibeju-Lekki urban) to 116.2 ± 28.9 mg/L (Ibeju-Lekki rural). Bicarbonates ranged from 114.9 ± 25.1 mg/L (Epe urban) to 171.0 ± 21.3 mg/L (Ibeju-Lekki rural). The mean levels of ammonia ranged from 0.2 ± 0.0 mg/L (Ibeju-Lekki urban) to 0.5 ± 0.4 mg/L (Ibeju-Lekki rural). There were significant differences ($p<.05$) in the mean values of EC ($p=.03$), TDS ($p=.02$), chloride ($p=.02$) and bicarbonate ($p=.05$) between Ibeju-Lekki rural and urban water samples. However, there was no significant difference ($p>.05$) in the mean values of pH, color,

Table 3. Physicochemical parameters and heavy metals level in the water samples from the study areas.

	Ibeju-Lekki		Epe		
Physicochemical Parameters	Rural	Urban	Rural	Urban	NSDWQ **Limits**
pH	9.6 ± 0.7	8.5 ± 0.1	7.8 ± 0.4	7.4 ± 0.4	6.5 - 8.5
Color (Pt/Co)	8.8 ± 2.8	7.1 ± 3.2	10.1 ± 2.7	6.0 ± 4.8	15
EC (µS/cm)	434.7 ± 106.2*	146.3 ± 120.2*	258.7 ± 126.7	107.7 ± 126.4	1000
TDS (mg/L)	218.3 ± 54.6*	95.3 ± 22.5*	129.0 ± 63.4	55.7 ± 62.8	500
Turbidity (NTU)	2.3 ± 1.0	1.5 ± 0.0	1.7 ± 0.3*	2.7 ± 0.3*	5
Sulfate (mg/L)	20.7 ± 7.7	8.4 ± 5.1	14.7 ± 7.7	6.1 ± 6.4	100
Nitrate (mg/L)	19.1 ± 8.1	8.6 ± 2.5	13.9 ± 5.4	7.5 ± 8.2	50
TOC (mg/L)	20.3 ± 19.1	20.0 ± 7.0	17.3 ± 7.4	23.0 ± 5.6	5
Chloride (mg/L)	116.2 ± 28.9*	51.5 ± 8.7*	67.3 ± 34.7	29.8 ± 31.8	250
Bicarbonate (mg/L)	171.0 ± 21.3*	135.7 ± 2.5*	115.7 ± 12.9	114.0 ± 25.1	150
Ammonia (mg/L)	0.5 ± 0.4	0.2 ± 0.0	0.3 ± 0.1	0.3 ± 0.2	N/S

	Ibeju-Lekki		Epe		Standards	
Heavy Metal (mg/L)	Rural	Urban	Rural	Urban	NSDWQ	WHO
Cd	0.02 ± 0.01	0.02 ± 0.02	0.04 ± 0.02*	BDL*	0.003	0.003
Cr	0.03 ± 0.002*	0.01 ± 0.01*	0.01 ± 0.01	0.00 ± 0.00	0.05	0.05
Fe	0.30 ± 0.20	0.10 ± 0.10	0.10 ± 0.10	BDL	0.3	0.3
Mn	0.03 ± 0.01	0.02 ± 0.02	0.2 ± 0.1	0.05 ± 0.05	0.2	0.05
Pb	0.02 ± 0.00	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.01	0.01
As	0.01 ± 0.01*	0.06 ± 0.01*	0.05 ± 0.01	0.04 ± 0.04	0.01	0.01
Co	0.02 ± 0.01	0.01 ± 0.00	0.05 ± 0.01	0.05 ± 0.01	–	–

Key: $n = 3$, NSDWQ (Nigerian Standard for Drinking Water Quality, 2007), WHO (World Health Organization, 2011), N/S = Not specified, BDL – below detection limit, * = Significant difference in mean concentration of parameters ($p < .05$). Values are presented as mean ± standard deviation.

turbidity, sulfate, nitrate, TOC and ammonia between Ibeju-Lekki rural and urban water samples. The *t*-test analysis also showed there was significant difference ($p < .05$) in the mean value of turbidity ($p = .01$) between Epe rural and urban water sources, while there was no significant difference ($p > .05$) in the mean values of pH, color, EC, TDS, sulfate, nitrate, TOC and ammonia between Epe rural and urban water samples (Table 3).

The results for the heavy metals analysis indicated that there was significant differences ($p < .05$) in the mean concentration of Cr ($p = .01$) and As ($p = .00$) in the water samples obtained from Ibeju-Lekki rural and urban areas. There was, however, no significant difference ($p > .05$) in the mean values of Cd, Fe, Mn, Pb and Co between Ibeju-Lekki rural and urban water samples. Furthermore, *t*-test also revealed that there was significant difference ($p < .05$) in the mean value of Cd ($p = .04$), while there was no significant difference ($p > .05$) in the mean values of Cr, Fe, Mn, Pb and As between Epe rural and urban water samples (Table 3).

Human health risk evaluation of drinking water from Ibeju-Lekki and Epe local government areas, Lagos

The human health risk assessment of heavy metals in the water samples showed that the calculated CDI of Cd and As exceeded the reference dose (RfD) for the rural and urban water samples examined in the study area (Table 4). The HQ for all the heavy metals tested was below 1 for both rural and urban water samples except for Cd and As. The HQ for cadmium in Ibeju-Lekki was 1.2 for both rural and urban water samples, while the HQ of cadmium in Epe rural water sample was 2. The HQ of As in the

Table 4. Human health risk assessment of heavy metals in water samples from the study areas.

		Ibeju-Lekki				Epe			
		Rural		Urban		Rural		Urban	
Heavy Metal	RfD (mg/kg/ day)	CDI (mg/kg/ day)	HQ	CDI (mg/kg/day)	HQ	CDI (mg/kg/day)	HQ	CDI (mg/kg/day)	HQ
Cd	0.0005	0.0006	1.2	0.0006	1.2	0.001	2	BDL	–
Co	0.005	0.0006	0.12	0.0006	0.12	0.0003	0.06	0.001	0.2
Cr	0.003	0.001	0.3	0.0003	0.1	0.0003	0.1	0.0001	0.03
Fe	0.7	0.008	0.01	0.003	0.004	0.003	0.004	BDL	–
Mn	0.14	0.0008	0.006	0.0006	0.004	0.006	0.04	0.001	0.007
As	0.0003	0.0003	1	0.002	6.7	0.001	3.3	0.001	3.3

Key: RfD – Reference dose (USEPA,2005), BDL: Below detection limit, Cd: Cadmium, Co: Cobalt, Cr: Chromium, Fe: Iron, Mn: Manganese, As: Arsenic, CDI: Chronic daily intake, HQ: Hazard quotient.

study area was 1 (Ibeju-Lekki rural), 6.7 (Ibeju-Lekki urban) and 3.3 (Epe rural and urban) (Table 4).

Discussion

Water is an indispensable resource for supporting life systems. This study revealed the quality of drinking water sourced from wells and boreholes in Epe and Ibeju-Lekki local government areas of Lagos, Nigeria. The choice of well and borehole as a preferred source of household water in the rural and urban areas respectively may be based on the perceived quality of the water. Although public taps are situated at various locations in the study areas, the majority of them were not functional, irregular and situated very far away from residents. The lack of treatment of the dominant drinking water sources might be due to perceived cleanliness of the water by the users. These results agree with the observation of Marks *et al.* (2013) concerning inaccessibility to potable water supply in many SSA countries. The disparity (burning versus waste collectors) in the methods of waste disposal between the rural and urban areas may be due to the low level of education in the rural communities. Another reason could be the non-availability or inaccessibility of government approved waste collectors which informed their choice of wastes disposal.

The mean heterotrophic bacteria counts of the water samples from the study area showed very high bacteria counts compared with the WHO standard of 1.0×10^2 cfu/mL (WHO 1996). This may be due to the lack of treatment of water sources identified in this study and as admitted by most respondents in the study areas. The bacteria species identified are consistent with those frequently encountered in bacteriological analysis of drinking water (Edokpayi *et al.* 2018). The presence of fecal coliforms identified well water from the rural areas in this study might be attributed to non-closure and lack of treatment of most wells (allowing the entry of particles from the surrounding), the use of contaminated containers to fetch water from the wells, shallowness of some of the wells and lack of household hygiene that may arise from having the wells close to latrines (Akinyemi *et al.* 2006). *Micrococcus luteus* and *Enterobacter aerogenes* are opportunistic pathogens in a number of infections and diseases particularly in immunosuppressed patients, infants, elderly and those in the terminal stages of other diseases

(Everest 2007). *E. aerogenes* is sought out to be one of the many key causes for extra-intestinal infections next to *E. coli*. There is no evidence that normal uses of drinking water supplies are a source of infection of *Pseudomonas aeruginosa* in the general population. However, the presence of high numbers of *P. aeruginosa* in potable water, notably in packaged water, has been associated with complaints about taste, odor and turbidity (Hardalo and Edberg 1997). *Klebsiella spp.* are not considered to represent a source of gastrointestinal illness in the general population through ingestion of drinking water. They are generally biofilm organisms and are unlikely to represent a health risk (Bartram *et al.* 2003). *Bacillus spp.* is often detected in drinking water supplies, even supplies treated and disinfected by acceptable procedures. This is largely due to the resistance of spores to disinfection processes. There is no evidence of waterborne *Bacillus spp*. infection (Bartram *et al.* 2003). Water treatment methods such as boiling, solar disinfection, ultraviolet light treatment and chlorination have proved to be effective in the removal of coliforms and other microorganisms from drinking water thereby making such water fit for drinking (Owamah *et al.* 2014).

Most of the physicochemical parameters (EC, turbidity, TDS, chlorides and nitrates) analyzed in water samples from the study areas were below the maximum permissible limits by NSDWQ (2007). However, the pH of water samples collected from rural communities in Ibeju-Lekki was above the recommended maximum limit of 8.5 (NSDWQ 2007). Drinking water with a pH level above 8.5 indicates that high levels of alkaline minerals are present. High alkalinity does not pose a health risk but can cause esthetic problems such as alkali taste to water (WHO/United Nations International Children's Fund 2010). Also, the mean concentrations of TOC in the study area exceeded the NSDWQ (2007) limit of 5 mg/L. TOC is used as an indicator of the natural organic matter (NOM) and inorganic matter (bromide) in water. All commonly used chemical disinfectants (such as chlorine, chlorine dioxide, chloramines and ozone) react with organic matter and/or bromide to varying degrees to form different disinfection byproducts (DBPs) such as trihalomethanes (THMs). People can be exposed to THMs in drinking water through ingestion of drinking water, inhalation of indoor air largely due to volatilization from drinking water, inhalation and dermal exposure during showering and bathing. THMs are suspected to have negative effects on birth such as low birth weight, intrauterine growth retardation in terms of births as well as gestational age and preterm delivery. THMs have also been found to be carcinogenic and mutagenic with the greatest amount of evidence being related to bladder cancer (Mohamadshafiee and Taghavi 2012).

The mean values of Cd, Pb and As in the study areas exceeded the maximum permissible limits by NSDWQ (2007) and WHO (2011). Heavy metals enter the environment via natural and anthropogenic means such as industrial discharges, mining, erosion, sewage discharge water, effluents, but the main route of exposure for most people is through food and water. The route of entry of these heavy metals in the drinking water samples in this study particularly in the rural areas may be due to the direct disposal of wastewaters into the streets which could percolate into the groundwater such as wells. In the urban areas, the proximity of wastewater drainage channels to boreholes and surface run-off may be routes of entry of the heavy metals into the boreholes. Household plumbing fixtures containing Pb may contribute to Pb in drinking water especially in the presence of corrosive water (Levallois *et al.* 2018; Pieper *et al.* 2018). Consistent exposure to heavy metals at low levels can cause adverse effects (Mudgal *et al.* 2010). Exposure to high doses of Pb could lead to kidney and brain damage and miscarriage in pregnant women; convulsion, organ and neurological damage in children; and reproductive dysfunctions in men (Khan *et al.* 2013).

Cadmium is naturally present in the environment in soils, air, sediments and in seawater. It is emitted into the air by industries using cadmium compounds for pigments, plastics, alloys and so on. Cadmium accumulates in the human body and affects the lungs, liver, kidney, brain and central nervous system. Other damages include hepatic toxicity, reproductive, hematological and immunological toxicities (Mudgal *et al.* 2010). The best described accident related to discharge of cadmium into water is the occurrence of Itai-Itai disease among residents along the Jintsu River in Japan. The residents were not only exposed to cadmium through drinking water but also through the rice grown in the contaminated water (Jing-Xiu *et al.* 2009). In Southwestern Nigeria, in Ogun and Osun states, concentrations of As have been detected above the permissible limits recommended by NSDWQ and WHO (Amori *et al.* 2013). Arsenic is a trace element found at variable concentrations in the atmosphere, soils and rocks, natural waters. It is one of the geologic sources of pollution in groundwater (Chen *et al.* 2017). Arsenic enters the body through the skin (dermal) and also through parental routes (placental transfer of the arsenic to the unborn fetus), but the central port of arsenic entry is by oral ingestion of contaminated foods and water and also through inhalation (Maduabuchi *et al.* 2007). Garba *et al.* (2012) reported that chronic arsenic poisoning can take 5–15 years to reveal depending upon the amount of arsenic ingested. The severe toxicity of arsenic compounds in humans is mostly a function of their rate of removal from the body (WHO 2011). Cobalt is an essential element for all living beings as it is the part of vitamin B12 molecule. There is no current standard limit for concentration of cobalt in drinking water. The mean concentrations of chromium in the water samples collected from the study area were below the NSDWQ and WHO permissible limit of 0.05 mg/L. The low concentration of chromium may be due to lack of mining and industrial activities in the area. Though there were no significant differences in the levels of Fe and Mn between the rural and urban areas of Ibeju-Lekki and Epe, it is noteworthy that the levels were at the exact limit of the NSDWQ and WHO for the rural areas. Particularly, Mn levels in water from the rural areas of Epe were higher than the WHO set limit. Similar results have been reported by Olaoye and Onilude (2009) in sachet-packaged drinking water from Western Nigeria. However, the high level of Mn in the rural areas of Epe may be due to geologic sources (Van Wendel *et al.* 2016).

The health risk assessment of heavy metals in the water samples showed that the calculated CDI of Cd and As exceeded RfD for the rural and urban water samples examined in the study area. The CDI values give an indication of possible toxicity of these heavy metals found in the aquifer of the area. This clearly indicates that As poses a serious health risk in the study area. The HQ for Pb was not estimated due to non-availability of a RfD value for it (Wu *et al.* 2018). It is estimated that 94% of diarrheal cases are preventable through modification of the environment including improving availability to safe drinking water, sanitation and hygiene (WHO 2007).

Conclusion

This study demonstrated that water from the boreholes was of higher quality compared to water obtained from the wells. The absence of fecal waterborne pathogens in the urban borehole samples is an indication of the microbial quality of borehole water in the study area. The high concentration of TOC in both rural well and urban borehole is, however, of serious concern and measures should be put in place to ensure the reduction in the concentrations of TOC in the study area. Effective water treatment techniques that can remove heavy metals and other physicochemical parameters from water should be encouraged especially during the rainy season. Indiscriminate dumping of wastes into the environment can lead to pollution of water bodies either through run-off into surface water or by infiltration into groundwater; hence, proper waste disposal methods should be encouraged. In order to achieve the UN Sustainable Development Goal 6 on clean water and sanitation by the next decade (2030), we recommend that frequent monitoring, treatment and stakeholders education on drinking water treatment techniques should be actively conducted particularly in rural areas in the state, country, region and continent.

Disclosure statement

The authors declare that they have no conflicts of interest.

ORCID

Temitope O. Sogbanmu http://orcid.org/0000-0002-8913-267X

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