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Health risk assessment of heavy metals in drinking water from Iponri water treatment plant, Lagos water corporation Nigeria

Emeka Chima OGOKO*,[1] Stella Amarachi ONYEMELUKWE,[2] Henrietta Ijeoma KELLE,[3] Ifunanya IROEGBULEM,[4] Donard EMEZIEM,[5] and Adebisi Akinyemi FAGBOHUN[6]

[1]*Department of Chemistry, National Open University of Nigeria, Jabi Abuja*
[2]*Central Drug Control Laboratory, National Agency for Food and Drug Administration and Control, Lagos, Nigeria*
[3]*Department of Chemistry, National Open University of Nigeria, Jabi Abuja*
[4]*Institute of Chartered Chemists of Nigeria (ICCON), Abuja Nigeria*
[5]*Department of Science Laboratory Technology, Temple-Gate Polytechnic Aba, Abia State*
[6]*Chemistry Advanced Research Center Sheds Science and Technology Complex Abuja*

Abstract. Urban water supplied from treatment plants can constitute public health problems if poorly treated or accidentally contaminated. Water quality and health risk assessment of water supplied from Lagos State water treatment plant was performed. Heavy metal concentration was determined using Atomic Absorption Spectrophotometer. The mean concentrations of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr were within the standard maximum permissible limits for drinking water quality. The mean estimated daily intake through oral ingestion of drinking water for Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr were 0.00024, 0.00117, 0.00158, 0.00665, 0.00736, 0.000271, 0.00148, 0.000563 and 0.000834 mg/kg bw/day respectively, but were within acceptable tolerable daily intake standards for adult population. The values of hazard quotients for the heavy metal in water samples were below one for adult population. Hazard indices of treated water samples were below the threshold value of one (HI < 1) while hazard indices of untreated and pre-treated water samples exceeded one, indicating possible associated potential health risks as a result of combined effects of the heavy metals through oral consumption water. Incremental life cancer risk values of Cd, Ni, As and Cr in all the three categories of water samples exceeded the safe limit for cancer risk while the cumulative cancer risk (ΣILCR) also exceeded the proposed threshold safe risk limit (> $1x10^{-4}$), indicating potential carcinogenic lifetime health risk in adult population through oral consumption of the heavy metal in water. Conclusively, the treated water had lowest levels of heavy metals, hazard quotient, incremental life cancer risks values and unsafe for drinking purposes compared to the untreated and pre-treated water.

***Keywords*:** heavy metals; concentration; incremental life cancer risks; water treatment plant.

1. Introduction

Water pollution is serious environmental issues which imposes serious threat to human health [1, 2]. Water is referred as palatable if it is sufficiently free from colour, turbidity, taste, odour, and within acceptable level of pH and dissolved solids [3, 4]. There are several contaminants that adversely affects drinking water quality however, heavy metals attract overwhelming attention because of their higher levels of toxicity even at very low concentrations. Metallic elements including transition metals, some metalloids, lanthanides and actinides with high atomic weight and density are referred to as heavy metals. Heavy metals are usually in particulate, colloidal and dissolved form in drinking water [5, 6]. The sources of heavy metals in water are eroded minerals, leaching of ore deposits and anthropogenic sources which include solid waste, industrial and municipal effluent and water channel dredging [7, 8]. Heavy metals have found their ways into surface water through mining, runoff from auto mechanic workshops and other industrial activities. Other anthropogenic sources that significantly contributes to heavy metals pollution in the environment include but not limited to smelting that emits arsenic, copper and zinc. Besides, automobile exhaust is known to discharge lead, insecticides relate to discharge of arsenic while combustion of fossil fuels was linked to the release of nickel, vanadium, mercury, selenium and tin in the environment [9]. The production processes of goods by man to meet the overwhelming demands of large population has immensely contributed to pollution status of the environment [10]. Lead contamination of tap water has been linked to contact of water with older lead pipes, lead solder, or brass fixtures containing lead metal [11]. Lead, mercury, arsenic, cadmium and chromium are the heavy metals related to human poisoning and toxicity, whereas copper, zinc, iron, nickel and manganese are actually required by the body in small amounts and hence essential for normal growth [12]. Essential metals such as zinc, calcium, magnesium, copper and iron are needed at low concentrations as catalyst for enzyme activities in the body. Food chains

* Corresponding author. *E-mail address*: eogoko@noun.edu.ng (Emeka Chima Ogoko)

and trophic levels are the main route through which heavy metal bio-accumulation within target organ of living organisms and can eventually pose serious health threat to human [13]. Many that can afford the cost of drilling private boreholes depend on this source of drinking water supply in Lagos while several others depend on metropolitan water supply by the state water board. The quality of drinking water supply may have been compromised due to uncoordinated water supply and the poor solid waste and sewage system as a result of insufficient waste water treatment and sanitation service in Lagos State. Besides, there is no effective strategies and institutional competences to create an enabling environment for a broader and safer water distribution system.

The aim of this study was to evaluate the levels of heavy metals in drinking water supplied to residents by Lagos State Water Cooperation Iponri, Surulere. Bioaccumulation of heavy metals generally in tissues or organs of the body could lead to adverse health effects in human such as Parkinson's disease, cancer, skin disorders, respiratory abnormalities, abdominal and intestinal abnormalities, central nervous system disorder, blood disorders and infertility [14]. Acute exposure to high levels of heavy metals could lead to nausea, anorexia, vomiting, gastrointestinal anomalies and dermatitis. However, each individual heavy metal has different health effects and symptoms to human health [15, 16]. The main objectives of the present study were to determine the concentrations of heavy metals including lead (Pb), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), cadmium (Cd), nickel (Ni), arsenic (As), and chromium (Cr) in drinking water distribution network of the water treatment plant Iponri Surulere areas of Lagos metropolis and to estimate the health risks associated with daily oral ingestion of these heavy metals.

2. Experimental

2.1. Study area description

Lagos state is located on the southwest coast of Nigeria and consists of Lagos Island (original city) as well as the mainland, which is made up of rapidly growing settlements. Lagos State has an area of about 1,341 square miles (3,400 km^2) of which half is water. Lagos has a population of over 20.19 million and is the main commercial center in Nigeria. Over 70 percent of the nation's industries and commercial activities are domicile in the state. This study was conducted in Lagos water cooperation treatment plant, Iponri Surulere. The geographical coordinates of the study area are 6.4983° N, 3.3610° E. The metropolitan area of Lagos is 385.9 square miles (999.6 km^2) while the water bodies including wetlands consists of over 22% of the total landmass in the Lagos metropolitan area.

2.2. Materials and sampling

All chemicals and reagents were of analytical grade. Nitric acid, HNO_3, was purchased from Sigma-Aldrich (Merck group) and used without additional purification. De-ionize double distilled water was used for preparation of solution and all dilution for standards. The entire glassware used in the present study were washed and oven dried at 110 °C. The sampling bottles were washed with metal free detergents, rinsed severally with deionized water, and soaked in 10% HNO_3 before taking in the samples. A total thirty water samples were collected from the Lagos water cooperation, Iponri Surulere and distribution network in the month of September, 2022 so as to measure the levels of selected heavy toxic metals. Out of the 30 water samples, 10 samples each were from untreated (raw borehole) water, pre-treated water (after sand bed and activated carbon filtration process) and treated water (tap water supplied to public for drinking purpose). The samples were then taken to the laboratory and stored at 4 °C prior to analysis.

2.3. Heavy metals determination

Heavy metals concentrations were analysed according to standard method of Official Method of Analysis [17, 18]. 10 mL mixture of concentrated HCl/HNO_3 in volume ratio 3:1 (aqua regia) was added to the sample and then heated to almost dryness. 20 mL of deionized water was added with vigorous stirring and then filtered. Heavy metals analysis of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As, and Cr were then performed at their respective wavelength (217, 228.9, 212, 248.3, 278, 227, 231, 193.7, and 358 nm) using the filtrates of the samples obtained after digestion by aid of flame furnace atomic absorption spectrophotometer (Schdmazu AA-6800, Tokyo, Japan). The limit of detection for Pb, Cu, Zn, Fe, Mn, Cd, Ni, As, and Cr was 0.001 ppm. The value of blank (deionized water) reading for all the metals was 0.000 ppm. Samples were analysed in triplicates and the mean of each triplicate analysis was recorded [19]. The spectrophotometer was operated under optimal conditions as follows: measurement mode (integrated), slit with (0.5 nm), gain (79%), lamp current (4.0 mA), flame type (air/acetylene), air flow (13.0 L/min), acetylene flow (3.8 L/min), optimum burner height (12 mm).

2.4. Method validation

The accuracy of heavy metals analysis was evaluated by spiking analyte samples with 0.5 mg/L of standard solutions of the corresponding metals prior to digestion. The spiked samples were then exposed to the same experimental conditions as the test sample and % recovery was then computed with the following equation:

$$Recovery\ \% = \frac{Concentration\ in\ spiked\ sample - Concentration\ in\ unspiked\ sample}{\text{Actual spike concentration (Amount reference standard added)}} \quad (1)$$

The calculated percentage recovery of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As, and Cr ranged from 90 – 100 %. The range of recovery were within the acceptable requirement of 75-120% [17, 18], which indicates the performance of the method. The linearity of the method or instrument linearity was evaluated by taking measurement of absorbance and the corresponding concentrations of ten standard solutions. Regression analysis shows good linearity of the range 0.9910 - 0.9967. The linearity curve has R^2 values higher than

0.990, indicating that the values are within acceptable limits. For reference intervals, the instrument was zeroed prior to each analysis but recalibrated with standard solutions after every 50 samples analysed. However, the standard reference interval was assessed statistically and followed the normal distribution curve as presented in Table 5. For precision of the method, the analysis was performed in triplicate n equals 3 and results presented as mean ± standard deviation. The mean inter-assay coefficient of variations (% CV = 3.861) was less than 15% while intra assay CV (n = 30) for Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr are 6.87, 5.385, 3.979, 0.837, 0.478, 7.667, 2.322, 3.21 and 4.004% respectively (Tables 1-3), which were less than 10%. The inter-assay and intra-assay coefficient of variations were within the generally acceptable range of less than 15% and 10% respectively, which reflect the performance of the assay in the hands of the user. The concept of sensitivity is the amount of signal per unit of the analyte. To this end, the instrument setting and operational conditions were performed in accordance with the manufacturers' specifications. The burner height was adjusted as the need arises, this allows the radiation beam to pass through the zone of highest atom cloud density in the flame, resulting in the highest sensitivity. The instrument automatically selects an appropriate lamp and optimization settings were activated. The optimum lamp current varies with cathode elements and lamp design but enhances selectivity. The most sensitive spectral line was automatically selected for measurement which consequently enhances the sensitivity of the analytical method or analysis.

2.5. Health risks assessment

Information on estimated daily intake, hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk are required in order to effectively evaluate the potential health risks associated with oral ingestion of heavy metals through drinking water.

2.5.1. Estimated daily intake (EDI). The estimated daily intake is expressed in mg/kgbw/day and can be calculated with the formulae below [20].

$$EDI = \frac{CR}{BW} \times IR \qquad (2)$$

where CR refers to metal concentration, IR and BW represent the daily water consumption rate and the mean body weight of an adult Nigerians respectively. The average body weights (BW) and the daily ingestion rate through oral consumption of water in adult Nigerian were taken as 64 kg and 2.0 L respectively [21, 22].

2.5.2. Non-carcinogenic risk. Non carcinogenic health risks of heavy metals were assessed by calculating the hazard quotient of each individual metal and the summation of all the hazard quotient of heavy metals in water is given as hazard index [23-25].

$$HQ = \frac{EDI}{RfD} \qquad (3)$$

where RfD is the oral reference dose expressed in mg/kg/day. Oral reference dose is the probable maximum permissible health risk connected with daily ingestion or contact with heavy metals by human. Oral reference dose values of Cd (0.001), Cr (0.003), As (0.0003), Ni (0.02), Hg (0.0001), Pb (0.004), Cu (0.04), Zn (0.3), Mn (0.14), Fe (0.70) and Co (0.02) are to be used in calculating the hazard quotients of corresponding heavy metals in the present study [23-25]. HQ < 1 indicates no potential non-carcinogenic health risk, whereas HQ > 1 indicates non-carcinogenic potential chronic health risk.

The hazard index (HI) is calculated with the formulae below:

$$\mathrm{HI} = \sum \mathrm{HQ} \qquad (4)$$

HI <1, indicates no potential health risk, whereas HI >1 indicates potential chronic health risk.

2.5.3 Carcinogenic risk. Incremental lifetime cancer risk ($ILCR$) can be used to access carcinogenic health risk and is computed with the equation below [25, 26].

$$ILCR = CDI\ x\ CSF \qquad (5)$$

where CDI is the chronic daily intake of carcinogenic heavy metals expressed in mg/kg bw/day while CSF refers to the cancer slope factor. Cancer slope factor for Pb, Ni, Cd, As and Cr are 0.009, 1.7, 0.6, 1.5 and 0.501 respectively [27-30].

$$\mathrm{CDI} = \frac{\boldsymbol{EDI\ x\ EF\ x\ ED}}{\boldsymbol{AT}} \qquad (6)$$

where EF is the expose frequency expressed in days/year (365 days per year), ED refers to the exposure duration in years or life expectancy. 54 years has been proposed as life expectancy for adult Nigerian [31]. AT is the average time or period of exposure [32]. AT is equivalent to 365 days per year multiplied by 54 years which gives a total of 19,710 days.

3. Results and discussion

The concentrations of heavy metals in untreated (raw) water from the Lagos water treatment plant Surulere are presented in Table 1. The concentrations of lead in untreated water ranged from 0.002 ± 0.0007 - 0.028 ± 0.0008 mg/L with average of 0.010 ±0.00062 mg/L. Although the average concentration of lead had the same value with the World Health Organisation and Nigeria Standard for Drinking Water Quality recommended limits (0.01 mg/L), while samples S2, S4, and S8 recorded higher concentrations values of 0.027 ±0.0008 mg/L, 0.028 ±0.0008 mg/L and 0.012 ±0.0005 mg/L respectively [33, 34].

Table 1. Heavy metals concentrations (mean ± SD) in untreated (raw) water from Lagos State water treatment plant

Parameter	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Ni (mg/L)	As (mg/L)	Cr (mg/L)
S1	0.004±0.0005	0.049±0.010	0.041±0.001	0.490±0.005	0.337±0.004	0.001±0.0002	0.056±0.003	0.003±0.001	0.037±0.003
S2	0.027±0.0008	0.079±0.003	0.061±0.003	0.182±0.003	0.431±0.002	0.001±0.0002	0.061±0.004	0.010±0.001	0.041±0.005
S3	0.008±0.0005	0.008±0.002	0.063±0.008	0.130±0.001	0.321±0.001	0.002±0.0002	0.045±0.001	0.007±0.001	0.026±0.001

Parameter	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Ni (mg/L)	As (mg/L)	Cr (mg/L)
S4	0.028±0.0008	0.007±0.001	0.006±0.002	0.156±0.003	0.389±0.005	0.003±0.0001	0.062±0.005	0.006±0.002	0.042±0.002
S5	0.004±0.0006	0.099±0.004	0.012±0.001	0.274±0.004	0.026±0.002	0.003±0.0002	0.054±0.002	0.001±0.001	0.035±0.002
S6	0.007±0.0004	0.018±0.003	0.018±0.003	0.405±0.005	0.343±0.004	0.003±0.0003	0.045±0.004	0.003±0.001	0.028±0.001
S7	0.005±0.0009	0.056±0.002	0.024±0.004	0.086±0.001	0.024±0.001	0.002±0.0002	0.036±0.001	0.002±0.001	0.019±0.001
S8	0.012±0.0005	0.018±0.003	0.030±0.001	0.173±0.002	0.315±0.003	0.001±0.0002	0.029±0.001	0.005±0.001	0.020±0.001
S9	0.004±0.0005	0.013±0.001	0.050±0.005	0.292±0.002	0.109±0.001	0.002±0.0002	0.038±0.002	0.004±0.002	0.024±0.001
S10	0.002±0.0007	0.012±0.001	0.190±0.009	0.234±0.005	0.267±0.002	0.002±0.0001	0.026±0.001	0.006±0.001	0.026±0.002
Mean	0.010±0.00062	0.036±0.003	0.050±0.003	0.242±0.002	0.256±0.0014	0.002±0.00019	0.045±0.0015	0.047±0.001	0.030±0.0012
CV (%)	6.200	8.333	6.00	0.8264	0.547	9.500	3.333	2.1277	4.00

The mean levels of Cu, Zn, Mn, Cd, Ni, As and Cr in untreated water were 0.036 ±0.003, 0.050 ±0.003, 0.256 ±0.0014, 0.002 ±0.00019, 0.045 ±0.0015, 0.047 ±0.001 and 0.030 ±0.0012mg/L respectively. These values were within the World Health Organisation and Nigeria Standard for Drinking Water Quality recommended limits for these metals in drinking water [33, 34]. The concentrations of Fe ranged from 0.130 ±0.001 - 0.490 ±0.005 mg/L in untreated (raw) water. The concentration of Fe was within the maximum permissible value (0.3 mg/L) in almost all the water samples except for S1 that had slightly higher values (0.490 ±0.005 mg/L) which may be due to corrosion process or residue rich in Fe(II) content arising from the post-coagulation stage of water treatment [32-34]. Although iron is an essential element required for human nutrition particularly in Fe(II) oxidation state however, water quality problems such as obnoxious red colouration can arise due to excessive corrosion of iron pipes and distribution systems. Deposition of a slimy coating on water pipes may occur because iron promotes the growth of iron bacteria which obtain energy from the oxidation of ferrous iron to ferric iron [35]. Zinc impacts an objectionable astringent taste to water which appear opalescent and develop a greasy film on boiling at concentrations in excess of 3–5 mg/L [35]. Zinc is one of the essential elements vital for healthy growth of both plants and humans. Manganese is associated with unpleasant taste in water and beverages in addition to staining of wares and laundry, black precipitated as well as coating on pipes at concentrations above 0.1 mg/L.

The heavy metals concentrations of pre-treated water from Iponri water treatment plant are presented in Table 2.

Table 2. Heavy metals concentrations (mean ± SD) of pre-treated water (after sand bed and activated carbon) water from Lagos State water treatment plant

Parameter	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Ni (mg/L)	As (mg/L)	Cr (mg/L)
S11	0.003±0.0005	0.025±0.002	0.006±0.001	0.475±0.006	0.282±0.003	0.002±0.0001	0.044±0.004	0.002±0.001	0.027±0.003
S12	0.021±0.0003	0.098±0.006	0.059±0.003	0.160±0.003	0.391±0.002	0.001±0.0001	0.053±0.002	0.008±0.002	0.033±0.002
S13	0.007±0.0005	0.023±0.001	0.035±0.002	0.101±0.002	0.302±0.002	0.001±0.0001	0.038±0.001	0.006±0.002	0.020±0.001
S14	0.022±0.0006	0.044±0.003	0.042±0.002	0.132±0.001	0.350±0.003	0.002±0.0001	0.057±0.003	0.004±0.001	0.038±0.002
S15	0.002±0.0005	0.060±0.003	0.056±0.004	0.256±0.002	0.101±0.001	0.001±0.0001	0.045±0.002	0.001±0.001	0.030±0.002
S16	0.005±0.0004	0.022±0.001	0.028±0.001	0.325±0.004	0.293±0.002	0.002±0.0001	0.039±0.005	0.002±0.001	0.028±0.003
S17	0.004±0.0003	0.051±0.002	0.038±0.002	0.074±0.001	0.021±0.001	0.001±0.0001	0.033±0.004	0.002±0.001	0.020±0.001
S18	0.011±0.0005	0.012±0.002	0.028±0.001	0.155±0.003	0.291±0.003	0.002±0.0002	0.031±0.003	0.004±0.002	0.018±0.002
S19	0.003±0.0006	0.011±0.002	0.048±0.001	0.281±0.005	0.099±0.002	0.001±0.0010	0.033±0.002	0.003±0.001	0.020±0.001
S20	0.002±0.0004	0.010±0.001	0.185±0.006	0.204±0.003	0.192±0.002	0.002±0.0001	0.025±0.002	0.004±0.001	0.023±0.002
Mean	0.008±0.00046	0.036±0.0015	0.053±0.0016	0.216±0.0016	0.232±0.001	0.002±0.0001	0.040±0.0012	0.004±0.001	0.026±0.001
CV (%)	5.75	4.167	3.019	0.7407	0.431	5.000	0.300	2.500	3.846

The concentrations of Pb ranged from 0.002 ±0.001 - 0.022 ±0.0005 mg/L with average value of 0.008 ±0.00046 mg/L. Lead concentrations in most of the water samples evaluated were lower than the recommended WHO provisional limit of 0.01 mg/L [32], except S12 (0.021 ±0.0003 mg/L), S14 (0.022 ±0.0006 mg/L) and S18 (0.011±0.0005 mg/L) that recorded slightly higher concentration values. In pre-treated water, the concentrations of Cu and Zn ranged from 0.010 ±0.001- 0.098 ±0.006 mg/L and 0.006 ±0.001 - 0.185 ±0.006 mg/L respectively. The concentrations of Cu and Zn were lower than the maximum permissible limits of 2.0 mg/L and 3.0 mg/L respectively [33, 34]. The concentrations of Mn, Cd, Ni, As and Cr ranged from 0.021 ±0.001- 0.391±0.002 mg/L, 0.001±0.0001 - 0.002 ±0.0001 mg/L, 0.025 ±0.002- 0.057 ±0.003 mg/L, 0.001 ±0.001 -0.008 ±0.002 mg/L and 0.018 ±0.002 - 0.032±0.003 mg/L respectively. The concentrations of Mn, Cd, Ni, As and Cr were below their respective WHO and NSDWQ maximum permissible limits [33, 34]. The concentrations of metals in treated water are presented in Table 3.

Table 3. Heavy metals concentrations (mean ± SD) of treated water from Lagos State water treatment plant

Parameter	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Ni (mg/L)	As (mg/L)	Cr (mg/L)
S21	0.004±0.0004	0.024±0.003	0.041±0.002	0.290±0.006	0.263±0.003	0.001±0.0001	0.040±0.002	0.001±0.001	0.020±0.002
S22	0.005±0.0003	0.079±0.004	0.061±0.003	0.166±0.003	0.371±0.003	0.001±0.0001	0.043±0.002	0.002±0.001	0.031±0.003
S23	0.004±0.0003	0.008±0.002	0.063±0.004	0.102±0.001	0.298±0.002	0.002±0.0004	0.039±0.001	0.003±0.001	0.022±0.002
S24	0.006±0.0002	0.044±0.006	0.006±0.001	0.122±0.002	0.330±0.004	0.003±0.0002	0.047±0.003	0.004±0.002	0.032±0.003
S25	0.004±0.0004	0.006±0.001	0.012±0.001	0.239±0.004	0.100±0.002	0.003±0.0003	0.045±0.003	0.001±0.001	0.028±0.002
S26	0.005±0.0005	0.081±0.004	0.018±0.001	0.255±0.004	0.270±0.004	0.003±0.0002	0.037±0.002	0.002±0.001	0.029±0.002
S27	0.003±0.0004	0.041±0.002	0.034±0.002	0.066±0.001	0.041±0.001	0.002±0.0001	0.032±0.001	0.002±0.001	0.020±0.003
S28	0.002±0.0002	0.010±0.001	0.023±0.001	0.125±0.002	0.270±0.003	0.001±0.0001	0.028±0.001	0.003±0.001	0.016±0.001
S29	0.002±0.0002	0.099±0.003	0.040±0.002	0.241±0.005	0.078±0.001	0.001±0.0001	0.030±0.002	0.005±0.003	0.018±0.002
S30	0.001±0.0003	0.016±0.003	0.182±0.005	0.194±0.003	0.170±0.002	0.002±0.0001	0.020±0.001	0.003±0.002	0.020±0.001
Mean	0.0037±0.00032	0.041±0.0015	0.048±0.0014	0.18±0.0017	0.219±0.001	0.002±0.00017	0.036±0.0012	0.003±0.00015	0.024±0.001
CV (%)	8.649	3.659	2.917	0.944	0.457	8.500	3.333	5.000	4.167

The mean concentrations of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr in treated water were 0.0037±0.00032, 0.041±0.0015, 0.048 ±0.0014, 0.18 ±0.0017, 0.219 ±0.001, 0.002±0.00017, 0.036 ± 0.0012, 0.003 ±0.00015 and 0.024 ±0.001 mg/L respectively. The concentrations of these metals were within the WHO and NSDWQ maximum permissible limits except for lead which was higher, hence, the water is not safe for drinking with respect to lead [33, 34]. The unusual high concentration of lead in treated water may be attributed to corrosion of lead-based service connections or pipeline and plumbing in buildings. Besides, there were instances of punctures and leakages in service connections close to some isolated sampling points that requires repair. Lead concentrations may vary depending on the contact period of water in the lead-containing materials. Exposure of Pb at high concentration can result to gastrointestinal tract, central nervous system disorders, kidney failure and ultimate death [4]. The maximum allowable limits of some selected heavy metals are presented in Table 4.

Table 4. WHO and NSDWQ allowable limit of some physiochemical parameters in portable water

Parameter	Pb (mg/L)	Cu (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Cd (mg/L)	Ni (mg/L)	As (mg/L)	Cr (mg/L)
WHO [33]	0.01	2.0	3.0	0.3	0.5	0.003	0.07	0.01	0.05
NSDWQ [34]	0.01	1.0	3.00	0.3	0.2	0.003	0.02	0.01	0.05

In a similar research carried out on heavy metal concentration of treated water from municipal water treatment plant in Gudi-Akwanga, Nasarawa State, the concentrations of Cd (0.005 mg/L), As (0.105 mg/L), Cr (0.124 mg/L), and Zn (0.573 mg/L) were found to be higher than the results of the respective heavy metals in this study [36]. In another study, the concentrations range of lead (0.00 - 0.076 mg/L), iron (0.996 - 17.789 mg/L) and Mn (0.666 - 1.382 mg/L) obtained from heavy metal analysis of raw, treated water and sludge samples from a treatment plant in Sokoto, Nigeria appeared to be higher than the concentrations of the respective heavy metals in the present study [37].

Table 5. Standard refence intervals

Metal	Standard Refence Intervals (mg/L)	
	Lower Limit	Upper Limit
Pb	-0.00236	0.00238
Cu	-0.00349	0.00362
Zn	-0.00325	0.00338
Fe	-0.00371	0.00435
Mn	-0.00191	0.00260
Cd	-0.00237	0.00237
Ni	-0.00280	0.00288
As	-0.00237	0.00237
Cr	-0.00235	0.00240

The standard refence intervals of mean metal concentrations for treated water were presented in terms of lower and upper limits in Table 5. The reference intervals of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr were -0.00236 to 0.00238 mg/L, -0.00349 to 0.00362 mg/L, -0.00325 to 0.00338 mg/L, -0.00371 to 0.00435 mg/L, -0.00191 to 0.00260 mg/L, -0.00237 to 0.00237 mg/L, -0.00280 to 0.00288 mg/L, -0.00237 to 0.00237 mg/L and -0.00235 to 0.00240 mg/L respectively. The reference intervals followed the normal statistical distribution.

Majority of Nigerians that could not assess municipal water supply networks in Lagos depend on borehole as a source of drinking water without any further purification or treatment. The risks analysis was done on the three categories of water samples (untreated, pretreated and treated water) because during the period of sampling in the present study, there were instances when disruption of water supply via the treated water service connections or pipeline occurred due to technical hitches, people living very close to the treated plant resulted to manually fetching of untreated (raw borehole) water for domestic uses including drinking. Comparison of risk analysis of the three categories of water samples therefore became necessary and attracted attention in the study. The estimated daily intake of heavy metals through oral consumption of water is presented in Table 6.

Table 6. Estimated daily intake of water from Lagos State water treatment plant (mg/kg bw/day)

Parameter	Pb	Cu	Zn	Fe	Mn	Cd	Ni	As	Cr
					Estimated daily intake of untreated (raw) water				
S1	0.000125	0.001530	0.001280	0.01530	0.0105	0.0000313	0.00175	0.0000938	0.00116
S2	0.000844	0.002470	0.001910	0.00569	0.0135	0.0000313	0.00191	0.000313	0.00128
S3	0.000250	0.000250	0.001970	0.00406	0.0100	0.0000625	0.00141	0.000219	0.000813
S4	0.000875	0.000220	0.000188	0.00488	0.0122	0.0000938	0.00195	0.000188	0.00131
S5	0.000125	0.003090	0.000375	0.00856	0.0813	0.0000938	0.00169	0.0000313	0.00109
S6	0.000219	0.000563	0.000563	0.00347	0.0107	0.0000938	0.00141	0.0000938	0.000875
S7	0.000156	0.001750	0.000750	0.00269	0.00075	0.0000625	0.00113	0.0000625	0.000594
S8	0.000375	0.000562	0.000938	0.00540	0.00984	0.0000313	0.000907	0.000156	0.000625
S9	0.000125	0.000406	0.001560	0.00912	0.00341	0.0000625	0.00119	0.000125	0.00075
S10	0.000063	0.000375	0.005940	0.00732	0.00835	0.0000625	0.000813	0.000188	0.000813
Mean	0.000313	0.001120	0.001560	0.00756	0.0080	0.0000625	0.00141	0.00147	0.000938
					Estimated daily intake of pre-treated water				
S11	0.000094	0.000656	0.000188	0.0148	0.00881	0.0000625	0.00191	0.0000625	0.000844
S12	0.000656	0.003060	0.001840	0.0050	0.0122	0.0000313	0.00141	0.00025	0.00103
S13	0.000219	0.000719	0.001090	0.00316	0.00944	0.0000313	0.00195	0.000688	0.000625
S14	0.000688	0.001380	0.001310	0.00413	0.0109	0.000688	0.00169	0.000125	0.00119
S15	0.000688	0.001880	0.001750	0.0080	0.00316	0.0000313	0.00141	0.0000313	0.0000938
S16	0.000156	0.000688	0.000875	0.0102	0.00916	0.000688	0.00113	0.000688	0.000875
S17	0.000125	0.001590	0.001190	0.00231	0.000656	0.0000313	0.000907	0.000688	0.000625
S18	0.000344	0.000375	0.000875	0.00484	0.00909	0.000688	0.00119	0.000125	0.000563

Parameter	Pb	Cu	Zn	Fe	Mn	Cd	Ni	As	Cr
S19	0.000094	0.000344	0.001500	0.00878	0.00309	0.0000313	0.000813	0.0000938	0.000625
S20	0.000688	0.000313	0.005789	0.00638	0.0060	0.000688	0.00141	0.000125	0.000719
Mean	0.000250	0.001130	0.001669	0.00675	0.00725	0.000688	0.00191	0.000125	0.000813
					Estimated daily intake of treated water				
S21	0.000156	0.000750	0.001280	0.00906	0.00822	0.0000312	0.00128	0.0000312	0.000625
S22	0.000156	0.002470	0.001910	0.00519	0.01160	0.0000312	0.00134	0.0000625	0.000969
S23	0.000250	0.000250	0.001960	0.00319	0.00931	0.0000625	0.00122	0.0000937	0.000688
S24	0.000219	0.001380	0.000188	0.00381	0.00103	0.0000937	0.00146	0.000125	0.0010
S25	0.000281	0.000188	0.000375	0.00747	0.00313	0.0000937	0.00141	0.0000312	0.000875
S26	0.000156	0.002530	0.000563	0.00797	0.00844	0.0000937	0.00116	0.0000625	0.000906
S27	0.000094	0.001280	0.001060	0.00206	0.00128	0.0000625	0.00100	0.0000625	0.000625
S28	0.000031	0.000313	0.007190	0.00391	0.00844	0.0000312	0.000875	0.0000937	0.00050
S29	0.000063	0.003090	0.001280	0.00753	0.00244	0.0000312	0.0000938	0.000156	0.000563
S30	0.000031	0.000500	0.005690	0.00606	0.00531	0.0000625	0.000625	0.0000937	0.000625
Mean	0.000156	0.001280	0.001500	0.00563	0.00684	0.0000625	0.00113	0.0000937	0.00075
Overall mean	0.00024	0.001170	0.001580	0.00665	0.00736	0.0002710	0.00148	0.000563	0.000834

The estimated daily intake in mg/kgbw/day for Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr through oral consumption of drinking water ranged from 0.000031 - 0.000844, 0.000188 - 0.00309, 0.000188 - 0.00719, 0.00206 - 0.0153, 0.000656 - 0.0813, 0.0000312 - 0.000688, 0.0000938 - 0.00195, 0.0000312 - 0.00147 and 0.0000938 - 0.00131 respectively.

The estimated daily intake of Pb, As, Cd, and Fe through oral consumption of drinking water were below the acceptable provisional tolerable daily intake of 0.00357, 0.0021, 0.00083 and 0.80 mg/kgbw/day respectively [37-40]. Similarly, the estimated daily intake of Cu was lower than 0.5 mg/kgbw/day proposed as the oral daily intake of copper from food [28]. There scanty information on the acceptable standard daily intake of Cr, Mn, Zn, and Ni by standard organization, however estimated daily intake of these metals in the study does not indicate any health risk.

The calculated Hazard quotient (HQ) and hazard index (HI) of heavy metals through oral consumption of water are presented in Table 7.

The mean HQ of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr in untreated water were 0.0783, 0.0281, 0.0052, 0.0108, 0.0571, 0.0625, 0.0705, 4.9000, and 0.3867 respectively.

Table 7. Hazard quotient (HQ) of drinking water from Lagos State water treatment plant

Parameter	Pb	Cu	Zn	Fe	Mn	Cd	Ni	As	Cr	HI=∑HQ
					Untreated (raw) water					
S1	0.0313	0.0383	0.0043	0.0219	0.0750	0.0313	0.0875	0.3127	0.3867	0.9888
S2	0.2100	0.0618	0.0064	0.0081	0.0964	0.0313	0.0955	1.0433	0.4267	1.9795
S3	0.0625	0.0063	0.0066	0.0058	0.0714	0.0625	0.0705	0.7300	0.2710	1.2866
S4	0.2188	0.0055	0.0006	0.0070	0.0871	0.0938	0.0975	0.6267	0.4367	1.5736
S5	0.0313	0.0773	0.0013	0.0122	0.5807	0.0938	0.0845	0.1043	0.3633	1.3487
S6	0.0548	0.0141	0.0019	0.0050	0.0764	0.0938	0.0705	0.3127	0.2917	0.9207
S7	0.0391	0.0438	0.0025	0.0038	0.0054	0.0625	0.0565	0.2083	0.1980	0.6199
S8	0.0938	0.0141	0.0031	0.0077	0.0703	0.0313	0.0454	0.5200	0.2083	0.9939
S9	0.0313	0.0102	0.0052	0.0130	0.0244	0.0625	0.0595	0.4167	0.2500	0.8726
S10	0.0156	0.0094	0.0198	0.0105	0.0597	0.0625	0.0407	0.6267	0.2710	1.1157
Mean	0.0783	0.0281	0.0052	0.0108	0.0571	0.0625	0.0705	0.4901	0.3867	1.1893
					Pre-treated water					
S11	0.0235	0.0164	0.0006	0.0211	0.0629	0.0625	0.0690	0.2083	0.3127	0.7771
S12	0.1640	0.0765	0.0061	0.0071	0.0871	0.0313	0.0830	0.8333	0.2813	1.5699
S13	0.0548	0.0180	0.0036	0.0045	0.0674	0.0313	0.0595	2.2933	0.3433	2.8758
S14	0.1720	0.0345	0.0044	0.0059	0.0779	0.6880	0.0890	0.4167	0.2083	1.6966
S15	0.1720	0.0470	0.0058	0.0114	0.0226	0.0313	0.0705	0.1043	0.3967	0.8616
S16	0.0390	0.0172	0.0029	0.0146	0.0654	0.6880	0.0610	2.2933	0.0313	3.2127
S17	0.0313	0.0398	0.0040	0.0033	0.0047	0.0313	0.0515	2.2933	0.2917	2.7508
S18	0.0860	0.0094	0.0029	0.0069	0.0649	0.6880	0.0485	0.4167	0.2083	1.5316
S19	0.0235	0.0086	0.0050	0.0125	0.0221	0.0313	0.0515	0.3127	0.1877	0.6548
S20	0.1720	0.0078	0.0193	0.0091	0.0429	0.6880	0.0391	0.4167	0.2083	1.6031
Mean	0.0625	0.0283	0.0055	0.0096	0.0518	0.6880	0.0625	0.4167	0.2397	1.5646
					Treated water					
S21	0.0390	0.0188	0.0043	0.0129	0.0082	0.0312	0.0640	0.1040	0.2083	0.4907
S22	0.0390	0.0618	0.0064	0.0074	0.0116	0.0312	0.0670	0.2083	0.3230	0.7557
S23	0.0625	0.0063	0.0065	0.0046	0.0093	0.0625	0.0610	0.3123	0.2293	0.7543
S24	0.0548	0.0345	0.0006	0.0054	0.0010	0.0937	0.0730	0.4167	0.3333	1.0130
S25	0.0703	0.0047	0.0013	0.0107	0.0031	0.0937	0.0705	0.1040	0.2917	0.6499
S26	0.0390	0.0633	0.0019	0.0114	0.0084	0.0937	0.0580	0.2083	0.3020	0.7860
S27	0.0234	0.0320	0.0035	0.0029	0.0013	0.0625	0.0500	0.2083	0.2083	0.5924
S28	0.0078	0.0078	0.0240	0.0056	0.0084	0.0312	0.0438	0.3123	0.1667	0.6076
S29	0.0156	0.0773	0.0043	0.0108	0.0024	0.0312	0.0047	0.5200	0.1877	0.8539
S30	0.0078	0.0125	0.0190	0.0087	0.0053	0.0625	0.0313	0.3123	0.2083	0.6677
Mean	0.0390	0.0320	0.0050	0.0080	0.0068	0.0625	0.0565	0.3123	0.2500	0.7722

The mean HQ of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr in pre-treated water was 0.0625, 0.0283, 0.0055, 0.0096, 0.0518, 0.6880, 0.0625, 0.4167 and 0.2397 respectively. The mean HQ of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr in treated water was 0.0390, 0.0320, 0.0050, 0.0080, 0.0068, 0.0625, 0.0565, 0.3123 and 0.2500 respectively. The hazard quotient of the three categories of water samples were less than threshold value of 1.0, signifying that there is no potential health risk linked to these heavy metals via oral consumption of water. The hazard indices (HI) in most untreated and pre-treated water samples were greater than one indicating likelihood of chronic health risk while values of hazard index in treated water samples were less than one (HI < 1), demonstrating that there is no potential chronic health risk associated with the heavy metals through oral consumption of water.

The computed values of incremental life cancer risk for adult population are shown in Table 8. The mean incremental lifetime cancer risk of Pb, Cd, Ni, As and Cr in the untreated drinking water correspond to 7.04E-04, 3.75E-02, 1.20E-01, 7.35E+00 and 1.94E-01. In pre-treated water, the mean incremental lifetime cancer risk of Pb, Cd, Ni, As and Cr were 5.63E-04, 4.13E-01, 1.06E-01, 6.25E-01, and 1.20E-01 respectively. The mean incremental lifetime cancer risk of Pb, Cd, Ni, As and Cr in fully treated water meant for public usage from the Lagos treated plant were 3.51E-04, 3.75E-02, 9.61E-02, 4.68E-01 and 1.25E-01 respectively. The proposed safe limit of cancer risk is 1 x 10^{-4} to 1 x 10^{-6} [23]. The mean values of Pb in untreated, pre-treated and treated water were within the safe limit and unlikely to constitute any carcinogenic health risk by consumption of water from these sources.

Table 8. Incremental lifetime cancer risk (ILCR) of carcinogenic human health risks through ingestion of water from the study area

Parameter	Pb	Cd	Ni	As	Cr	Σ ILCR
			Untreated water			
S1	2.82E-04	1.88E-02	1.49E-01	4.69E-01	1.94E-01	8.31E-01
S2	1.89E-03	1.88E-02	1.62E-01	1.56E+00	2.14E-01	1.96E+00
S3	5.63E-04	3.75E-02	1.20E-01	1.10E+00	1.36E-01	1.39E+00
S4	1.97E-03	5.63E-02	1.66E-01	9.40E-01	2.19E-01	1.38E+00
S5	2.81E-04	5.63E-02	1.44E-01	1.56E-01	1.82E-01	5.39E-01
S6	4.93E-04	5.63E-02	1.20E-01	4.69E-01	1.46E-01	7.92E-01
S7	3.52E-04	3.75E-02	9.61E-02	3.12E-01	9.92E-02	5.45E-01
S8	8.44E-04	1.88E-02	7.71E-02	7.80E-01	1.04E-01	9.81E-01
S9	2.81E-04	3.75E-02	1.01E-02	6.25E-01	1.25E-01	8.89E-01
S10	1.41E-04	3.75E-02	6.91E-02	9.40E-01	1.36E-01	1.18E+00
Mean	7.04E-04	3.75E-02	1.20E-01	7.35E+00	1.94E-01	7.70E+00
			Pre-treated water			
S11	2.11E-04	3.75E-02	1.17E-01	3.12E-01	1.57E-01	6.24E-01
S12	1.48E-03	1.88E-02	1.41E-01	1.25E+00	1.41E-01	1.55E+00
S13	4.93E-04	1.88E-02	1.01E-01	3.44E+00	1.72E-01	3.73E+00
S14	1.55E-03	4.13E-01	1.51E-01	6.25E-01	1.04E-01	1.29E+00
S15	1.55E-03	1.88E-02	1.20E-01	1.56E-01	1.99E-01	4.95E-01
S16	3.51E-04	4.13E-01	1.04E-01	3.44E+00	1.57E-02	3.97E+00
S17	2.81E-04	1.88E-02	8.76E-02	3.44E+00	1.46E-01	3.69E+00
S18	7.74E-04	4.13E-01	8.24E-02	6.25E-01	1.04E-01	1.23E+00
S19	2.11E-04	1.88E-02	8.76E-02	4.69E-01	9.40E-02	6.70E-01
S20	1.55E-03	4.13E-01	6.64E-02	6.25E-01	1.04E-01	1.21E+00
Mean	5.63E-04	4.13E-01	1.06E-01	6.25E-01	1.20E-01	1.26E+00
			Treated water			
S21	3.51E-04	1.87E-02	1.09E-01	1.56E-01	1.04E-01	3.88E-01
S22	3.51E-04	1.87E-02	1.14E-01	3.12E-01	1.62E-01	6.07E-01
S23	5.63E-04	3.75E-02	1.04E-01	4.68E-01	1.15E-01	7.25E-01
S24	4.93E-04	5.62E-02	1.24E-01	6.25E-01	1.67E-01	9.73E-01
S25	6.32E-04	5.62E-02	1.20E-01	1.56E-01	1.46E-01	4.79E-01
S26	3.51E-04	5.62E-02	9.86E-02	3.12E-01	1.51E-01	6.18E-01
S27	2.11E-04	3.75E-02	8.50E-02	3.12E-01	1.04E-01	5.39E-01
S28	7.02E-05	1.87E-02	7.44E-02	4.68E-01	8.35E-02	6.45E-01
S29	1.41E-04	1.87E-02	7.97E-03	7.80E-01	9.40E-02	9.01E-01
S30	7.02E-05	3.75E-02	5.31E-02	4.68E-01	1.04E-01	6.63E-01
Mean	3.51E-04	3.75E-02	9.61E-02	4.68E-01	1.25E-01	7.27E-01

However, the values of incremental life cancer risk of Cd, Ni, As and Cr in all the three categories of water samples evaluated were higher than the safe limit for cancer, indicating there is possibility of potential carcinogenic health risk by these heavy metals as a result of consumption of water from these sources in adult population. The cumulative cancer risk (ΣILCR) for each of the three categories of drinking water samples exceeded the suggested threshold risk limit (> $1x10^{-4}$) establishing the likelihood of developing cancer through ingestion of these metals during a lifetime in Nigeria adult population.

4. Conclusions

The mean concentrations of Pb, Cu, Zn, Fe, Mn, Cd, Ni, As and Cr in treated water distributed for drinking and other domestic purposes in Lagos were within the maximum permissible limits. Estimated daily intake of the heavy metals through oral ingestion of drinking water were within acceptable tolerable daily intake standards for adult population and less likely cause any health risk. The hazard quotient for each heavy metal in water samples was less than one for adult population. Hazard indices of heavy metals in treated water samples were less than one (HI < 1). The incremental lifetime cancer risk of each carcinogenic metal in water samples was greater than standard safe limit for cancer risk, except lead. There is high probability of potential incremental lifetime cancer risk through oral ingestion of these heavy metal in water by adult population in Lagos, Nigeria.

Conflicts of interest. The author declares no conflict of interest.

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