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Groundwater (Borehole water) Pollution by Heavy Metals and Physicochemical Parameters in and around a Major Tertiary Institution in Akoka Area of Lagos-State, Nigeria.

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Abstract

This study assessed the quality of borehole water in and around a tertiary institution in Akoka, Lagos State, Nigeria, by analyzing Heavy metals and Physicochemical parameters. Forty (40) Borehole water samples were collected from ten locations per month between June and November, 2023. Samples were digested with HNO_3 and analyzed using Atomic Absorption Spectrometry (AAS). Results showed that Lead (Pb) (1.22 - 3.44 mg/L) and Cadmium (Cd) (0.019 - 0.023 mg/L) exceeded WHO and NIS limits, while Zinc (Zn) (0.1015 - 0.1489 mg/L) remained within safe levels. Copper (Cu) and Nickel (Ni) were not detected. Pb (94%) was the most abundant metal, and Zn (4.98%) was the least. Kosoko Drive (KD) had the highest contamination, while Onos Hostel(OH) had the lowest. Physicochemical parameters - pH (4.50 - 6.83), temperature (29.2 - 30.1°C), total dissolved solids (106.2 - 436.7 mg/L), electrical conductivity (207 - 876 µS/cm), dissolved oxygen (4.18 - 5.09 mg/L), biological oxygen demand (0.38 - 1.10 mg/L), and chemical oxygen demand (2.48 - 5.24 mg/L) met WHO and NIS standards, although the water was acidic. Correlation analysis revealed a positive relationship between Heavy metals and Physicochemical parameters. Pollution indices (HPI, PI, MI) confirmed significant contamination. Therefore, the borehole water is polluted and unsafe for drinking or domestic use without adequate treatment.

Keywords: *Contamination, Pollution, Physicochemical, Heavy Metals, Concentration, Borehole.*

1. Introduction

The failure of Federal, State, and Local Governments, especially the Lagos State Water Corporation (LWC), to provide adequate water has forced Akoka residents in Lagos State to rely on groundwater (borehole water). Water, a transparent, tasteless, odorless, and colorless substance, is essential for life and socio-economic development, supporting food production, sanitation, and ecosystems (Talabi andKayode, 2021). Water sources are classified as -groundwater, such as boreholes, wells and surface water, including streams and reservoirs (Nnaji et al., 2016). Water from these sources serve domestic, agricultural, and industrial needs, each requiring specific quality standards to ensure safety and suitability (Saheed et al., 2021).

Akoka, located in Lagos Mainland Local Government Area, is a culturally diverse community with ethnic groups such as the Yoruba, Igbo, and Hausa, reflecting Nigeria's multicultural identity (Adeyemi, 2017). Bordered by Bariga, Shomolu, and Gbagada, it is known as a hub of academic excellence in Lagos State. The presence of a major university has spurred the growth of small and medium - sized businesses like cybercafés, shops, and transport services, boosting the local economy (Adeniran, 2019).

Groundwater in Akoka is primarily sourced from Lagos Lagoon and is part of the coastal aquifer system, a vital groundwater reserve in the region (Adeyemi, 2017). Boreholes typically access deeper confined aquifers, known for better water quality than shallow ones (wells). Due to the Lagos State Water Corporation's (LWC) inability to meet growing demand, residents increasingly rely on borehole water as a more dependable alternative to the often erratic municipal supply (Lagos State Ministry of Water Resources, 2020; University of Lagos, 2018).

Groundwater contamination by heavy metals, such as Copper (Cu), Zinc (Zn), Nickel (Ni), Cadmium (Cd), and Lead (Pb), along with other Physicochemical parameters, has become a significant environmental and public health concern in and around a tertiary institution in the Akoka area of Lagos State, Southwestern Nigeria. Even at low concentrations, long-term exposure to these metals poses serious health risks (Krishna et al., 2009). These contaminants originate from both natural and anthropogenic sources, including industrial activities, mining, agriculture, and improper waste disposal (Nawab et al., 2017; Bharati and Bhatnagar, 2018). Borehole water, polluted with these metals, may lead to serious health sicknesses, such as cancer, hypertension, gastrointestinal bleeding, neurological disorders, reproductive issues, and lung

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diseases (Lu et al., 2015; Nkpa et al., 2018). Lead is harmful, especially to children, as it can cause developmental delays, learning difficulties, and behavioral issues even at low levels of exposure (WHO, 2017). Adults, exposed to lead over time, may suffer from kidney damage, respiratory and skin problems, hypertension, and cognitive decline (Khan and Hanjra, 2009). Nickel, commonly found in industrial areas, especially in stainless steel and battery production, is a known carcinogen and often enters groundwater through industrial waste or plumbing. Copper contamination arises from corroded pipes, agricultural fungicides, and industrial discharges, leading to gastrointestinal problems in the short term and liver and kidney damage in the long term (Schaeffer and Frantzen, 2001). Zinc and Cadmium, mainly from mining, smelting, and battery production, also pollute groundwater and can cause kidney damage (WHO, 2017). Various laboratory methods are used to detect and quantify these metals in groundwater, they include inductively coupled plasma mass spectrometry (ICP-MS), flame atomic absorption spectrometry (FAAS), graphite furnace atomic absorption spectrophotometry (AAS-GF), and direct extraction/air acetylene flame methods (Faisal et al., 2014; Rahmanian et al., 2015). In addition to metal concentrations, physicochemical parameters, such as pH, temperature, turbidity, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO) are essential in assessing groundwater quality (WHO, 2011; Edwin et al., 2015). Deviations from WHO standards suggest pollution or environmental imbalance. For example, abnormal pH levels may signal acidic or alkaline contamination, while high EC and TDS indicate an excess of dissolved salts or pollutants. High levels of BOD and COD point out to organic or chemical contamination that could threaten aquatic life and public health (Tchounwou et al., 2012; Nriagu and Pacyna, 1988).

While numerous studies have assessed Heavy metals and Physicochemical parameters in groundwater across Lagos State and other areas of the world (Ezeribe et al., 2012; Behailu et al., 2017; Adefemi and Awokunmi, 2010; Shigut et al., 2017; Popoola et al., 2019), limited literature exists specifically in the Akoka area, with no literature particularly in and around a major tertiary institution located there (Adeniran, 2019; Olawole, 2015). Akoka was selected for this study due to its access to academic resources (Adeyemi and Ayodele, 2018), a diverse student population (Okunade and Olamide, 2017), a multicultural environment (Afolayan and Olumide, 2020), opportunities for collaboration (Anibueze, 2020; Oloyede and Abiola, 2022), and the presence of technological innovation (Abiodun and Madu, 2020). The influence of the institution on local developments (Uche and Bakare, 2021) also makes it a suitable case study. This research aims to assess the levels of heavy metals-Copper (Cu), Zinc (Zn), Nickel (Ni), Cadmium (Cd), Lead (Pb), and physicochemical parameters in borehole water and determine its safety for human consumption and domestic use without prior treatment.

2. Materials and Methods:

2.1 Description of Study Area/ Sampling Locations

This study was conducted in and around a tertiary institution in Akoka Area of Lagos State, Southwestern Nigeria. (N 6⁰ 30' 00" and E 3⁰ 23' 00"E - N 6⁰ 31' 30" and E 3° 24' 30"). The area is located in the center of Lagos metropolis and is low-lying with variations in terrain relief, which makes it susceptible to flooding during rainfall. The study area includes Chapel (CH), Makama hostel (MAH), Moremi hostel (MH), Eni-Njoku hostel (EH), human resource (HR), Onos hostel (OH), Kosoko drive (KD), Anglican church (AC), Omitogun Onike (OO), and Mountain of Fire Ministry Onike (MFO).

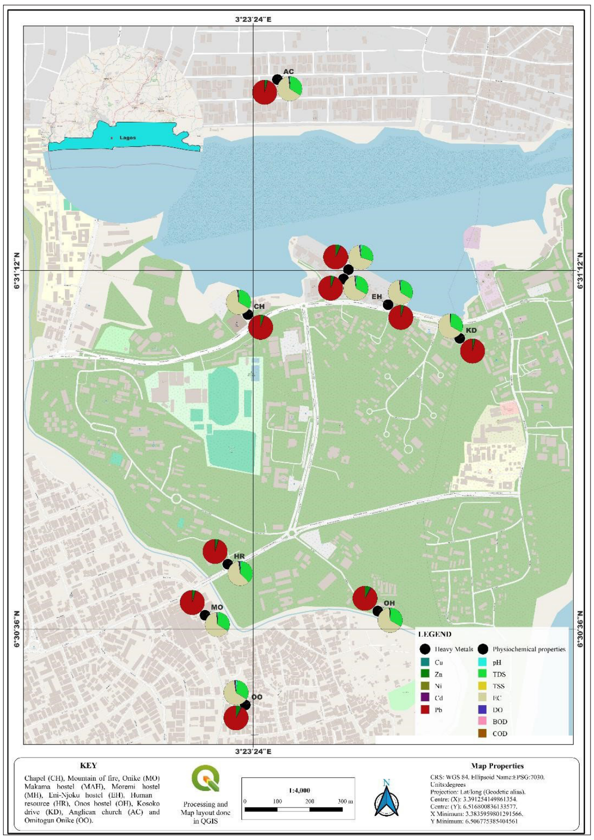

Figure 1. GIS Map showing the Sites and Concentrations of Heavy metals and Physicochemical parameters in the Study Area.

2.2 Selection of Sampling Sites/ Locations

Ten (10) Sampling sites were carefully chosen based on anthropogenic activities that may impact on the water quality in and around a tertiary institution in Akoka Area of Lagos - State, Southwestern-Nigeria. A Global Positioning System (GPS) device was used to record the coordinates for each sampling site.(GPS 76S Garmin)).

2.3 Sampling and Sample Collection

Ten borehole water Samples were collected in and around a tertiary institution in Akoka Area of Lagos-State, Southwesternn - Nigeria. Sampling was carried out for six months (June - November, 2023) and the samples were collected four times per month. The borehole water samples were collected with the aid of plastic bottles that has been previously washed and rinsed thoroughly with distilled water and suspended at one end to dry. The sample containers were first washed three times with each water sample before collection and the containers were tightly covered and labelled with appropriate identification codes. After collection, the samples were transported in an ice chest to the laboratory and analyzed for Heavy metals concentration (Cu, Zn, Ni, Cd, and Pb) and physicochemical parameters (pH, T0C, TDS, TSS, EC, DO, BOD, and COD).

2.4 Laboratory Analysis

All chemicals and reagents (Tetraoxosulphate (vi) acid (H2SO4), Trioxonitrate (v) acid (HNO3), Hydrochloric acid (HCl), Mercuric sulphate (HgSO4), Potassium dichromate (K2Cr2O7), Distilled water, Ferroin indicator, Ferrous ammonium sulphate (0.25 M FAS), Ethanol, Hydrogen peroxide) used for the laboratory analysis were of analytical grade and purchased from Lazco Scientific in Lagos, Lagos - State. Nigeria. Laboratory analysis were conducted inside the Analytical Chemistry Laboratory of the College Central Research Laboratory,Yaba College of Technology, Yaba - Lagos, Nigeria.

2.4.1 Digestion of Water Samples for Heavy metals Analysis

Borehole water samples were thoroughly shaken, and 100 mL of each was transferred to a 250 mL Pyrex beaker. Ten milliliters of concentrated HNO_3 were added, and the solution was gently heated and evaporated to about 20 mL. Then, 5 mL of concentrated HNO_3 and 5 mL of H_2O_2 were added, and the beaker was covered with a watch glass. The mixture was further heated until white fumes evolved and a clear solution formed. After cooling to room temperature, distilled water was added, and the solution was filtered using Whatman paper. The filtrate was transferred into a 100 mL volumetric flask, diluted to the mark with distilled water, mixed well, and stored in polypropylene bottles for analysis. Heavy metals (Cu, Zn, Ni, Cd, and Pb) were analyzed using an Agilent 240AA Atomic Absorption Spectrophotometer. All samples, including blanks and standards, were treated similarly. Triplicate analyses were performed for accuracy and precision (APHA, 2017; AOAC, 2000; Ajiwe and Eboagu, 2021).

2.5 Analysis of Physicochemical Parameters

2.5.1 Procedure for the Measurement of Temperatute, pH and Electrical Conductivity (EC)

The temperature, pH, and electrical conductivity of the water samples were determined by collecting 50 mL of each sample into a 100 mL beaker. The instrument used was an Adwa (AD 8000) pH/Conductivity/Temperature meter. The meter was inserted into the beaker, and readings were recorded. Electrical conductivity was expressed in µS/cm according to the machine's manual instructions. The meter was standardized using deionized water by inserting the electrodes into it. The water samples were analyzed for conductivity by immersing the probe in the beaker containing each sample, and the readings were taken (APHA, 2017; U.S. EPA, 2009; Baird et al., 2017; Perpetual et al., 2022).

2.5.2 Procedure for the Measurement of Dissolved (DO) and Biological Oxygen Demand(BOD)

The collected borehole water samples were tied in a black nylon immediately after collection to prevent light from penetrating into it and it was transported to the laboratory. Then, the initial dissolved oxygen (i.e. day zero (0) was measured using a portable dissolved oxygen meter (DO METER) and the values were recorded. Thereafter, the samples were incubated for five days in a dark cupboard, and date and time of incubation were noted. After incubation, the final dissolved oxygen (i.e. the quantity of oxygen used by the microbes within the five days) was measured using the same dissolved oxygen meter (DO METER) and the values were recorded. (APHA, 2017; U.S. EPA, 1993; Aliyu et al., 2018).

The Biological Oxygen Demand (BOD) were calculated, thus:

BOD (Mg/L) for day 5 = Final DO5 - Initial DO1

2.5.3 Procedure for the Measurement of Chemical Oxygen Demand(COD)

Chemical Oxygen Demand were determined using open reflux. 50.0 mL of each borehole water samples and distilled water (blank) were measured and transferred in a round bottom flask. 1g of Mecuric sulphate (HgSO4) and 25.0 mL K2Cr2O7 (0.00417M) were added and mixed. This was followed by slow addition of 75ml of Concentrated Tetraoxosulphate (vi) acid to the mixture. It was then heated at reflux for 2 hours and allowed to cool. The cooled solution was diluted with 350 ml distilled water and then cooled to room temperature. Then the excess Potassium dichromate (K2Cr2O7) in it was determined by titrating with 0.25 M Ferrous ammonium sulfate (FAS) using Ferroin indicator. A blank determination as above was done using 50ml of distilled water. (APHA, 2017;. U.S. EPA, 1983; Sawyer et al., 2003; Ovonkimwen, 2020).

The Chemical Oxygen Demand (COD) were calculated, thus:

$$\text{COD (mg/L)} = \frac{\mathbf{(A-B)\ x\ M \times 8000}}{\mathbf{Volume\ of\ the\ sample\ (ml)}}$$

Where: A = mL of Ferrous ammonium sulphate (FAS) used for the blank; B = mL of FAS used for the sample;

M = Molarity of the FAS. :

2.5.4 Procedure for the Determination of Total Suspended Solids (TSS)

Total Suspended Solids (TSS) were obtained gravimetrically by filtration. An aliquot (100ml) of the water sample was filtered through dried pre-weighed 0.45 filter paper placed in a Buchner funnel. After wards, the filter paper was over dried at 1050c for one hour. Then the filter paper was cooled and weighed. The difference in filter paper weight before and after was used to calculate the total suspended solid. (APHA, 2017; U.S. EPA, 1979; Sawyer et al., 2003; Arafat et al., 2021).

The Total Suspended Solids (TSS) were thus:

TSS (mg/L) = (final wt - initial wt) × 1000 / amount of the sample taken.

2.5.5 Procedure for the Determination of Total Dissolved Solids (TDS)

Total Solids (TS) and Total Suspended Solids (TSS) were determined before calculating Total Dissolved Solids (TDS). A 100 mL borehole water sample was evaporated in a dish over a water bath. The residue was dried at 106 °C in an oven, cooled, and weighed. This process was repeated twice to achieve a constant weight. The difference in weight before and after drying gave the TS value. TDS was calculated by subtracting TSS from TS. (APHA (2017);U.S.EPA (1979)).

The Total Dissolved Solids (TDS) were calculated thus:

TDS (mg/L) = Total Solids (TS) - Total Suspended Solids (TSS):

2.6 Statistical Analysis

The Mean, Standard deviation, Analysis of variance (ANOVA) and Pearson's Correlation Coefficient Analyses were conducted. Significant differences in Heavy metals and Physicochemical parameters were compared using Duncan Multiple Range Test (DMRT), a post - ANOVA method for identifying which group means differ significantly. Differences were indicated using superscripts (a, b, etc.) in Table 1. The results showed no significant relationship ($p > 0.05$) between Heavy metals and Physicochemical parameters across all sites, except for electrical conductivity, which showed a significant correlation. (Table 1).

Table 1. Mean ± Standard Deviation of Heavy metals and Physicochemical parameters in and around a tertiary institution in Akoka Area of Lagos - State, Southwestern - Nigeria.

Location/ Site	pH	TEMP (°C)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)	TDS (mg/L)	TSS (mg/L)	EC (µS/cm)	DO (mg/L)	BOD (mg/L)	COD (mg/L)
CH	5.04±3.35^{a}	29.40±13.51^{a}	0.15±0.15^{a}	0.02±0.01^{a}	2.99±1.61^{a}	162.00±159.35^{a}	0.01±0.012^{a}	323.00±176.35^{b}	4.36±1.20^{a}	0.91±1.11^{a}	3.72±1.57^{a}
MFO	5.30±3.23^{a}	30.10±12.01^{a}	0.12±0.15^{a}	0.02±0.01^{a}	2.78±2.62^{a}	187.10±158.40^{a}	0.01±0.006^{a}	366.67±168.81^{b}	4.41±1.13^{a}	0.38±0.52^{a}	2.84±1.15^{a}
MAH	5.88±2.73^{a}	28.97±13.25^{a}	0.13±0.12^{a}	0.06±0.12^{a}	1.83±1.68^{a}	106.18±87.92^{a}	0.01±0.005^{a}	254.00±166.29^{b}	4.58±1.75^{a}	0.47±0.42^{a}	3.32±1.34^{a}
MH	5.23±2.64^{a}	29.40±9.50^{a}	0.12±0.11^{a}	0.02±0.01^{a}	2.10±1.29^{a}	151.90±120.04^{a}	0.01±0.004^{a}	296.00±164.69^{b}	5.09±1.35^{a}	0.37±0.49^{a}	3.08±1.43^{a}
EH	6.06±2.96^{a}	29.47±10.79^{a}	0.13±0.16^{a}	0.02±0.00^{a}	3.01±1.47^{a}	177.10±149.41^{a}	0.02±0.019^{a}	339.33±223.94^{b}	4.71±1.95^{a}	0.86±0.97^{a}	2.48±1.53^{a}
HR	4.50±2.73^{a}	29.70±11.10^{a}	0.11±0.15^{a}	0.02±0.00^{a}	2.41±1.32^{a}	126.50±124.23^{a}	0.01±0.01^{a}	220.67±150.89^{b}	4.18±1.70^{a}	0.69±0.68^{a}	3.08±1.45^{a}
KD	6.13±2.35^{a}	29.40±11.89^{a}	0.11±0.09^{a}	0.02±0.01^{a}	3.44±2.10^{a}	277.20±235.08^{a}	0.03±0.026^{a}	876.00±506.08^{a}	4.47±1.59^{a}	0.91±0.98^{a}	5.24±1.81^{a}
AC	6.50±2.89^{a}	29.50±12.94^{a}	0.11±0.12^{a}	0.02±0.00^{a}	3.12±1.93^{a}	176.20±134.79^{a}	0.01±0.009^{a}	348.00±312.24^{b}	4.51±1.91^{a}	0.92±0.97^{a}	3.72±1.71^{a}
OH	5.12±3.03^{a}	29.20±11.51^{a}	0.11±0.13^{a}	0.02±0.01^{a}	3.37±2.02^{a}	319.10±233.93^{a}	0.02±0.019^{a}	484.33±330.93^{b}	4.60±1.36^{a}	1.10±1.01^{a}	4.84±1.94^{a}
OO	6.83±3.32^{a}	29.40±13.25^{a}	0.11±0.11^{a}	0.02±0.01^{a}	1.33±0.94^{a}	117.60±124.38^{a}	0.01±0.006^{a}	233.00±179.20^{b}	4.67±1.50^{a}	0.90±1.09^{a}	3.64±1.40^{a}
F-Statistics (p)	0.414 (0.934)	0.003 (1.000)	0.067 (1.000)	0.813 (0.617)	1.336 (0.235)	1.200 (0.312)	1.995 (0.052)	3.259 (0.002)	0.212 (0.994)	0.730 (0.693)	1.758 (0.091)

3. Results and Discussion

3.1 Heavy metals in Borehole water Sample

Copper (Cu) is an essential heavy metal that supports bodily functions but becomes toxic at high levels. It can enter drinking water from copper pipes, industrial waste, or algal control additives. Cu may cause nausea, vomiting, diarrhea, and liver or kidney damage at high concentrations (Peter and Funmilayo, 2016). In this study, Cu was not detected in any of the water samples, possibly due to the absence of copper-related anthropogenic activities in the sampling areas (Figure 1).

Zinc (Zn) was the least abundant Heavy metal in the analyzed water samples, with concentrations ranging from 0.1015 mg/L to 0.1489 mg/L and an average of 0.1199 mg/L. The highest concentration was recorded at Chapel (CH), while the lowest was at Onus Hostel (OH). All Zn concentrations were below the permissible limits set by WHO (2015) and NIS (2007), with no significant differences between the sites ($p > 0.05$). The high levels of Zn at CH may results from natural sources or anthropogenic activities, such as the use of fertilizers and wood preservatives. Zinc, though essential for human and plant health, can cause stomach pain, vomiting, fever, fatigue, and diarrhea at toxic levels (Hassan, 2016). At moderate levels, Zinc is generally non-toxic (Peter and Funmilayo, 2016). Zinc enters groundwater through industrial processes, including the galvanic and battery industries, or from Zinc-containing fertilizers (Gopi et al., 2023; Bux et al., 2022) (Table 2).

Nickel (Ni) was not detected in all the borehole water samples (Table 2), likely due to the absence of sources such as steel alloys, electroplating, batteries, electronics, and related industrial or household activities at the sampling sites (Rashid et al., 2021).

Cadmium (Cd) concentrations in the analyzed water samples ranged from 0.019 to 0.023 mg/L, with an average of 0.019 mg/L. EH has the highest Cd levels, while MAH had the lowest (Table 2). All borehole water samples in the study sites have average values exceeding the maximum permissible limit for Cd in drinking water (WHO, 2015; NIS, 2007).

Table 2. Average Mean Concentration of Heavy metals and Physicochemical parameters of Borehole Water in and around a tertiary institution in Akoka Area of Lagos - State, Southwestern - Nigeria.

S/N	SAMPLE CODE	pH	Temp	HEAVY METALS					TDS	TSS	EC	DO	BOD	COD
				Cu	Zn	Ni	Cd	Pb						
			°C	*mg/L*					*mg/L*	*mg/L*	µs/cm	*mg/L*		
1	**CH**	5.04	29.4	ND	0.1489	ND	0.022	3.16	162.0	0.011	323	4.36	0.91	3.72
2	**MFO**	5.30	30.1	ND	0.1192	ND	0.020	2.90	187.1	0.008	370	4.41	0.38	2.84
3	**MAH**	5.88	29.3	ND	0.1281	ND	0.019	1.85	106.2	0.007	254	4.58	0.42	3.32
4	**MH**	5.23	29.4	ND	0.1175	ND	0.020	2.18	151.9	0.006	306	5.09	0.47	3.08
5	**EH**	6.06	29.5	ND	0.1321	ND	0.023	3.07	177.1	0.017	353	4.71	0.86	2.48
6	**HR**	4.50	29.7	ND	0.1094	ND	0.021	2.52	126.5	0.014	207	4.18	0.69	3.08
7	**KD**	6.13	29.4	ND	0.1131	ND	0.021	3.44	436.7	0.028	876	4.47	0.91	5.24
8	**AC**	6.50	29.5	ND	0.1222	ND	0.020	3.25	176.2	0.010	348	4.51	0.83	3.72
9	**OH**	5.12	29.2	ND	0.1015	ND	0.021	1.22	319.1	0.019	640	4.60	1.10	4.84
10	**OO**	6.83	29.4	ND	0.1062	ND	0.020	1.38	117.6	0.008	233	4.67	0.90	3.64
	MEAN	5.66	29.5	ND	0.1199	ND	0.019	2.50	196.04	0.013	391	4.56	0.75	3.60
	WHO, 2015	6.5 - 8.5	30- 32	2.00	5.00	0.02	0.003	0.01	500		<1000	5	6	10
	NIS, 2007	6.5 - 8.5	30 - 32	1.00	3.00	0.02	0.003	0.01	500		1000	3 - 5	1.34	32.0

ND = Not detected

The high concentration of Cd in the borehole water samples resulting from galvanized steel pipe corrosion, leaching of contaminated soil, or industrial discharges involving plastics and fertilizers in the study area may cause lung damage, severe stomach pain, vomiting, and diarrhea (Yusuf et al., 2018). There were no significant variation in Cd concentrations across the study sites ($p > 0.05$).

Lead (Pb) was the most abundant Heavy metal in the analyzed water samples, with concentrations ranging from 1.22 to 3.44 mg/L and an average of 2.50 mg/L. The highest level was recorded at KD (3.44 mg/L), while the lowest was at OH (1.22 mg/L) (Table 2). All the borehole water samples have the Pb levels exceeding the maximum allowable limits set by WHO (2015) and NIS (2007), indicating serious contamination (Table 2). The high concentrations of Pb resulting from nearby mechanic workshops and fuel leakage from cars and generators could be due to anthropogenic activities such as traffic congestion, vehicle emissions, and leaching of Pb - containing waste into groundwater(Figure 2). There is no significant differences in Pb concentrations across the study sites ($p > 0.05$).

Lead exposure poses serious health risks, including cancer, nervous system damage, and brain disorders (Yusuf et al., 2017).(Figure 1). High exposure may also lead to anemia, muscle weakness, and stomach pain (Alani et al., 2014). Even at lower levels, Pb can harm children's mental and physical development, causing learning disabilities and seizures. The findings underscore the need for urgent water treatment and regulation of lead - emitting activities in the study area. The high concentrations of Pb, Zn, and Cd in the borehole water samples indicate significant contamination. In contrast, the absence of Cu and Ni suggests minimal sources or the water's inability to retain these metals. While Cu and Ni were not detected, the concentrations of Pb, Zn, and Cd were comparable to values reported in previous studies in different cities/locations of the world, with Pb being higher (Table 3). Although, the Physicochemical parameters in the study area fall within WHO (2015) and NIS (2007) permissible limits, the values were generally lower than those reported in similar studies from other cities or locations in the world. (Table 4).

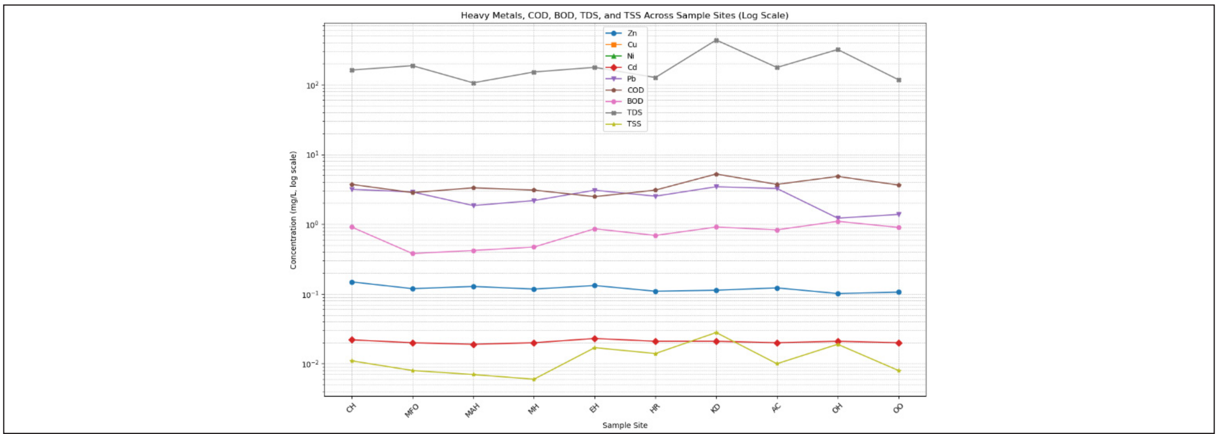

Figure 2. Line graph Showing the Concentrations of heavy metals and physicochemical parameters in the study Area.

Table 3. Data of Heavy metals in Borehole water in previous studies in different cities/locations of the world.

Heavy metals(mg/L)	Sample location										WHO permutable range	Previous studies / References
	CH	MFO	MAH	MH	EH	HR	KD	AC	OH	OO		
Cu	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.00	**ND -Not Detected - Present Study** 0.18 - 0.44 - Popoola et al., 2019. 8.04 - 24.0 - Ezeribe et al., 2012. 0.012 - 0.176 - Behailu et al., 2017. 0.26 - 0.38- Adefemi and Awokunmi,2010.
Zn	0.1489	0.1192	0.1281	0.1175	0.1321	0.1094	0.1131	0.1222	0.1015	0.1062	5.00	**0.1015 - 0.1489 - Present Study** 0.182 - 0.911 - Popoola et al., 2019. 0.001 - 1.054 - Birke et al., 2010. 5.692 - 12.421 - Fakayode, 2005.
Ni	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02	**ND - Not Detected - Present Study** 0.006 - 0.49 - Dinakaron et al., 2021. 0.019 - 0.04 -Tadiboyina and Prasada, 2016)
Cd	0.022	0.020	0.019	0.020	0.023	0.021	0.021	0.020	0.021	0.020	0.003	**00.019 - 0.023 - Present Study** 0.000 - 0.0025 - Popoola et al., 2019. 0.013 - 0.026 - Shigut et al., 2017. 0.000 - 0. 006 - Dinakaran et al., 2021
Pb	3.16	2.90	1.85	2.18	3.07	2.52	3.44	3.25	1.22	1.38	0.01	**1.22 - 3.44 - Present Study** 0.082 - 0.374 - Popoola et al., 2019. 0.071 - 0.122 - Faisal et al., 2014. 0.068 - 0.103 - Saddozai et al., 2009. 0.001 - 0.002 - Eruola and Adedokun , 2012.

ND = Not detected

Table 4. Data of Physicochemical parameters in Borehole water in previous studies in different cities/locations of the world.

Physico-chemical	Sample Locations										WHO permutable range	Previous studies / References
Properties	CH	MFO	MAH	MH	EH	HR	KD	AC	OH	OO		
pH	5.04	5.30	5.88	5.23	6.06	4.50	6.13	6.50	5.12	6.83	6.5 - 8.5	**4.50 - 6.83 - Present Study** 6.35 - 8.31 - Popoola et al., 2019. 6.10 - 6.77 - Oyem et al., 2014. 5.80 - 7.50 - Edwin et al., 2016. 5.57 - 8.00 - Ayodeji et al., 2017.
T °C	29.4	30.1	29.3	29.4	29.5	29.7	29.4	29.5	29.2	29.4	30 - 32°C	**29.2 - 30.1 - Present Study** 18.90 - 29.37- Okeke et al., 2021.
TDS (mg/L)	162	187.1	106.2	151.9	179.1	126.5	436.7	176.2	319.1	117.6	500.00	**106.2 - 436.7 - Present Study** 247.5 - 589.7 - Popoola et al., 2019. 390 - 1756.67 - Behailu et al., 2017. 166 - 184 - Ezeribe et al., 2012. 450 - 1350 - Buridi and Gedala, 2014.
TSS (mg/L)	0.011	0.008	0.007	0.006	0.017	0.014	0.028	0.010	0.019	0.008		**0.006 - 0.028 - Present Study** 0.01 - 0.02 Igbemi et al, 2019
E_C (µs/cm)	323	370	254	306	353	207	876	348	640	233	<1000	30.15 - 109.33 Odu et al, 2020 **207 - 876 - Present Study** 450 - 1190 - Popoola et al., 2019. 42.69 - 320 - Okoro et al., 2012. 333 - 1527 - Ikeme et al., 2014. 566.33 - 627.33 - Shigut et al., 2017.
BOD (mg/L)	0.91	0.38	0.42	0.47	0.86	0.69	0.91	0.83	1.10	0.90	6	**0.38 - 1.10 - Present Study** 1.20 - 4.30 - Popoola et al., 2019. 4.70 - 8.90 - Obi and Okocha, 2007. 1.60 - 5.0 - Adefemi and Awokunmi, 2010.
COD (mg/L)	3.72	2.84	3.32	3.08	2.48	3.08	5.24	3.72	4.84	3.64	10	**2.48 - 5.24 - Present Study** 5.90 - 9.00 - Amaria, 2015 51.0 - 93.0 - Oyem et al., 2014 37.0 - 49.0 - Patil and Patil, 2010. 7.0 - 28.0 - Eid, 2019.
DO (mg/L)	4.36	4.41	4.58	5.09	4.71	4.18	4.47	4.51	4.60	4.67	5	**4.18 - 5.09 - Present Study** 6.48 - 7.15 - John et al, 2024. 6.6 - 7.5 - Adeogun et al, 2019.

The variations in heavy metal levels and Physicochemical parameters when compared with previous studies in different cities/locations of the world may be due to differences in human activities (waste burning/dumping), environmental policies, and technology use. The distribution pattern of heavy metals in the sampled borehole water follows the order: Pb > Zn > Cd, with mean concentrations of 2.50, 0.1199, and 0.019 mg/L respectively. Kosoko Drive (KD) (3.57 mg/L) was the most polluted site, while Onos Hostel (OH) (1.34 mg/L) was the least (Figure 3). The high pollution levels in KD may result from vehicular emissions and mechanic workshops, releasing metal particles and petroleum products into the environment. The trend and Percentage contribution of each site to pollution are as follows: KD > AC > CH > EH > MFO > HR > MH > MAH > OO > OH (Figure 4). There were significant differences in heavy metal levels across the sites ($p < 0.05$). These findings align with similar studies by Okorie et al., 2024; Igbemi et al., 2019; Popoola et al., 2019; Opaluwa et al., 2020; and Odu et al., 2020, confirming that anthropogenic activities significantly influence groundwater contamination.

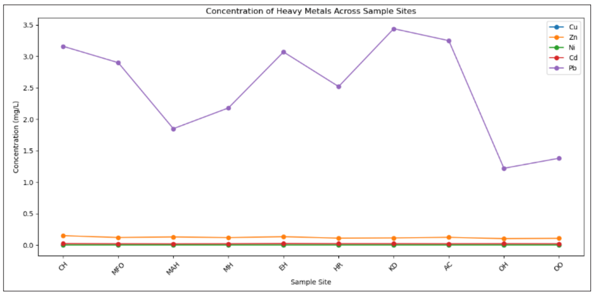

Figure 3. Line graph showing the distribution of heavy metals in the study area.

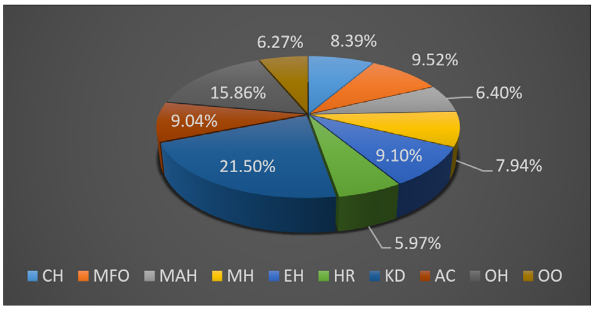

Figure 4. Percentage contribution of heavy metals and Physicochemical properties in each site.

3.2 Physicochemical Parameters of Borehole Water Sample

pH is a measure of the acidity or alkalinity of a solution, ranging from 0 to 14. In this study, borehole water pH ranged from 4.50 to 6.83, with an average of 5.66. The highest pH value was recorded at site OO, which was within WHO (2015) and NIS (2007) standards limits, while the lowest was at HR, falling below the acceptable limit (Table 2). Most water samples were acidic and below permissible limits, posing potential health risks. Acidic water can lead to the formation of carbonic acid in the body, making blood acidic and potentially harming health (Raji et al., 2019). There is no significant differences in pH values of the borehole water samples across the study sites ($p > 0.05$). The acidity of groundwater may be due to factors, such as increased temperature, high CO_2 concentrations from global warming, acidic soils, surrounding bedrock, and acid rain. Acidic conditions can also cause natural metals to dissolve, resulting in acid mine drainage and elevated metal concentrations in the water (Kitt, 2000).

Temperature is an important factor influencing metabolic activities, gas solubility, chemical reaction rates, and the distribution of aquatic organisms. In this study, borehole water temperatures ranged from 29.2°C to 30.1°C, with the highest value at MFO and the lowest at OH. These temperatures likely reflect the prevailing environmental and climatic conditions during sampling (Gebresilasie et al., 2021). All the borehole water temperature values were within the permissible limits set by WHO (2015) and NIS (2007). There was no significant difference in temperature across the study sites ($p > 0.05$). High water temperature will accelerate chemical reactions in aquifers, such as rock weathering, leading to the release of chemical contaminants. It can also reduce dissolved oxygen (DO) levels, potentially affecting aquatic ecosystems (Hassan et al., 2016; Maliki et al., 2020; Gebresilasie et al., 2021). Thus, monitoring temperature is essential for assessing water quality and its potential effects on both ecosystems and human health.

Total dissolved solids (TDS) are key indicators of drinking water quality. In the borehole samples, TDS ranged from 106.27 mg/L at MAH to 436.7 mg/L at KD, averaging 196.04 mg/L (Figure 5). High TDS may result from accumulated organic and inorganic solids, which can reduce water portability and cause gastrointestinal irritation or laxative effects. Therefore, the high TDS value in borehole water may be aesthetically displeasing for bathing and washing (Vincent, 2016). All TDS values in this study were within permissible limits set by WHO (2015) and NIS (2007), with no significant differences across sites ($p > 0.05$). TDS levels were consistently higher than total suspended solids (TSS) at all locations (Kaizer and Osakwe, 2010) (Figure 6). High TDS levels may indicate groundwater contamination from wastewater discharge into ponds and pits (Baloguru and Senthi, 2013).

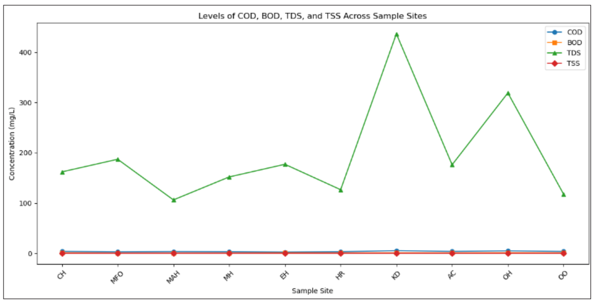

Figure 5. Line graph showing the distribution of Physicochemical parameters

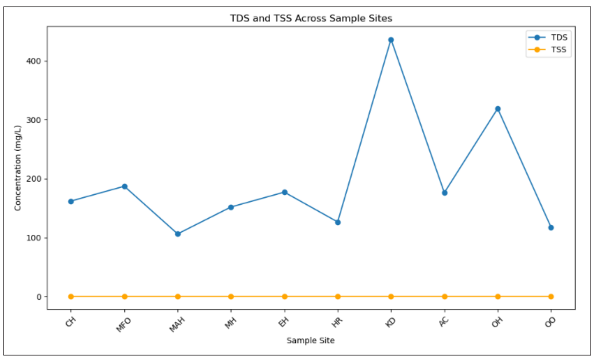

Figure 6. Line graph Showing the Levels of TDS and TSS in the Study Area

TSS is vital in determining water quality (Ndefo, 2011). It affects water clarity, so the higher the TSS value in a water source is, the lesser the clarity will be (WHO, 2017). The total suspended solids (TSS) values in the borehole water samples ranged from 0.006 mg/L at MH to 0.028 mg/L at KD, with an average value of 0.013 mg/L. In this study, the recorded results showed that TSS values were below the acceptable limit for drinking water quality(WHO, 2015; NIS, 2007). There is no significant difference in TSS levels in the study sites.($p > 0.05$).

Electrical conductivity (EC) measures water's ability to conduct electricity. It is determined by the presence of ionic species (Gebresilasie et al., 2021; Nriagu and Pacyna, 1988). Higher ion concentrations result in higher conductivity (Christine et al., 2018). EC values in this study ranged from 207 µS/cm at HR to 876 µS/cm at OH, averaging 391 µS/cm (Figure 7). All samples were within permissible limits set by WHO (2015) and NIS (2007) for drinking water. EC is directly related to total dissolved solids (TDS) because it reflects the ionic content of water, which determines its electrical conductivity (Figure 7). As TDS increases, ionic strength rises, causing higher EC values. High EC indicates contamination from dissolved ions, as EC is proportional to total dissolved solids (Gebresilasie et al., 2021). Monitoring EC helps assess water quality and detect possible pollution.

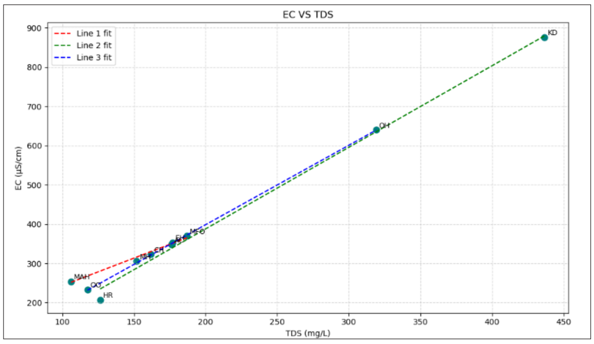

Figure 6. Line graph showing the relationship between EC against TDS

Dissolved oxygen (DO) is a key water quality indicator, reflecting contamination levels. Low DO suggests microbial contamination or chemical corrosion in the aquifer (Gebresilasie et al., 2021). DO concentrations ranged from 4.18 mg/L at HR to 5.09 mg/L at MH, averaging 4.56 mg/L. All the DO values in the borehole water samples were within acceptable limits (WHO, 2015; NIS, 2007) except at MH, which slightly exceeded the limit (Table 2). There was no significant difference in DO levels across all the sites ($p > 0.05$) (Table 1).

Biological oxygen demand (BOD) measures oxygen used by microorganisms to decompose organic matter, while chemical oxygen demand (COD) measures oxygen needed to oxidize both biodegradable and non-biodegradable materials. The BOD values in the borehole water samples ranged from 0.38 to 1.10 mg/L and COD from 2.48 to 5.24 mg/L, both were below permissible limits (WHO, 2015; NIS, 2007). There were no significant differences in BOD and COD levels across the study sites ($p > 0.05$) (Table 1).

3.3 Assessment of Pollution Status of Borehole Water Samples through Water Quality Indices

Water quality indices is a comprehensive tool used to assess water quality according to all metals present (Adano et al., 2023, Giri and Singh, 2014; Yadav et al., 2015).). To assess the pollution status, three water quality indices were applied this include: Heavy metals pollution index (HPI), Pollution index (PI), and Metal Index (MI).

3.3.1 Heavy Metal Pollution Index (HPI)

The Heavy Metal Pollution Index (HPI) is a ranking method used to assess the combined impact of individual heavy metals on overall water quality (Mohammed et al., 2014). The characterization of the borehole water from the study area with the use of the Heavy Metal Pollution index gives value to be compared with the critical value to evaluate the level of pollution (Yusuf et al., 2018) (Table 5).

Table 5. Mean of Heavy Metal Pollution of Borehole Water Samples in and around a Tertiary Institution in Akoka Area of Lagos - State, Southwestern - Nigeria.

S/N	Heavy metals	Mean Concentration MC (mg/L)	Highest Permissible value(Si), (NIS, 2007)	Unit weightage (Wi) Wi =	Sub index Qi =	Wi × Qi
1	Zinc (Zn)	0.11982	3.0	0.333	3.994	1.330
2	Cadmium(Cd)	0.0207	0.003	333.333	690	229999.77
3	Lead (Pb)	2.473	0.01	100	24730	2473000
4	Copper(Cu)	ND	ND	ND	ND	ND
5	Nickel	ND	ND	ND	ND	ND
HPI= $\frac{\sum Wi \times Qi}{\sum Wi}$ = 6232.91				$\sum$Wi=433.666		$\sum$Wi Qi =2703001.1

The mean HPI value was found to be 6232.91 which were far above the critical value of 100. This value indicates that the water from the study area is highly polluted with respect to Heavy metals and therefore unsuitable for consumption and domestic use.

3.3.2 Pollution Index (PI).

PI provides information on the relative pollution contributed by each sample. When the critical value is greater than 1.0. It shows a significant degree of pollution whereas value less than 1.0 indicates no pollution. The results showed high PI values for Cadmium (Cd) at 6.9 and Lead (Pb) at 247.3, both exceeding 1.0, indicating significant pollution (Ajiwe and Eboagu, 2021) (Table 6).

Table 6. Pollution Index (PI) of Borehole water Samples

S/N	Heavy metals	Mean Concentration	W.H.O Limit (2017)	PI = $\frac{\text{Concentration}}{\text{Standard}}$
1	**Zinc (Zn)**	0.11982	5.0	0.02
2	**Cadmium(Cd)**	0.0207	0.003	6.9
3	**Lead (Pb)**	2.473	0..01	247.3
4	**Copper (Cu)**	ND	ND	ND
5	**Nickel (Ni)**	ND	ND	ND
$\sum$PI = 254.22				

In contrast, Zinc (Zn) had a pollution index of 0.02, suggesting no pollution. Since, the values of PI of Pb and Cd were above 1.0, suggesting that the borehole water samples if consume may cause serious health risks because the higher the values of PI, the higher the rate of the hazard risk on the human body (Girl and Singh, 2015).

3.3.3 Metal index (MI)

The Metal Index (MI) assesses the impact of heavy metals on human health and overall drinking water quality (Caeiro et al., 2005). The higher the concentration of a metal is when compared to its respective MAC value, the worse the quality of water will be. MI value > 1 is a threshold of warning (Yusuf et al., 2018). The MI values for Zn, Cd, and Pb are 0.02, 6.9 and 247.3 respectively, while Ni and Cu were not detected. The MI values for the Heavy metals showed that the water is seriously polluted with Pb and Cd. MI for the study area indicates low quality water with value 254.2 (Table 7). Therefore, the borehole water samples in the study area are considered unsafe for consumption and domestic use (Caerio et al., 2005).

Table 7. Metal index (MI)

S/N	Heavy metals	Mean5 Concentration MC	Highest Permitted Limit (WHO, 2017)	$MC = \frac{MC}{HPI}$
1	**Zinc (Zn)**	0.11982	5.0	0.02
2	**Cadmium (Cd)**	0.0207	0.003	6.9
3	**Lead (Pb)**	2.473	0.01	247.3
4	**Copper (Cu)**	ND	ND	ND
5	**Nickel (Ni)**	ND	ND	ND
$\sum$MI = 254.2				

Table 8. Water Quality Classification using MI (Caerio et al., 2005)

Metal index (MI)	Characteristics	Class
< 0.3	Very pure	1
0.3 – 1.0	Pure	11
1.0 – 2.0	Slightly affected	111
2.0 – 4.0	Moderately affected	1V
4.0 – 6.0	Strongly affected	V
>6.0	Seriously affected	VI

3.4 Correlation Coefficient Analysis.

Pearson's significant correlation analysis was employed to evaluate the relationship between the concentrations of heavy metals and physicochemical parameters in and around a tertiary institution in Akoka area of Lagos-State. The correlation coefficient values range from 0.052 to 0.946. There is a positive significant relationship between each of the heavy metals ($p < 0.05$) (Kaizer and Osakwe (2010); Zhang et al. (2021). Similarly, there is a positive significant relationship between each of physicochemical parameters ($p < 0.05$)(Orebiyi et al. (2022). Generally, here is positive significant relationship between the heavy metals and physicochemical parameters ($p < 0.05$) (Table 9).

Table 9. Correlation Coefficient Analysis of the heavy metals and physicochemical parameters in Borehole Water in and around a tertiary institution in Akoka Area of Lagos - State.

	pH	Temp (°C)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)	TDS(mg/L)	TSS(mg/L)	EC(µS/cm)	DO(mg/L)	BOD(mg/L)	COD(mg/L)
pH	1	.924** (<0.001)	.873** (<0.001)	.335** (<0.001)	.802** <0.001)	.707** (<0.001)	.592** (<0.001)	.579** (<0.001)	.881** (<0.001)	.780** (<0.001)	.794** (<0.001)
Temp (°C)		1	.946** (<0.001)	.389** (<0.001)	.823** <0.001)	.743** (<0.001)	.675** (<0.001)	.637** (<0.001)	.936** (<0.001)	.823** (<0.001)	.821** (<0.001)
Zn (mg/L)			1	.312* (0.011)	.810**(<0.001)	.754**(<0.001)	.648**(<0.001)	.563**(<0.001)	.910**(<0.001)	.804**(<0.001)	.745**(<0.001)
Cd (mg/L)				1	0.240(0.052)	0.181(0.145)	0.126(0.313)	0.186(0.134)	.365** (0.003)	0.052(0.680)	.251* (0.042)
Pb (mg/L)					1	.634** (<0.001)	.562** (<0.001)	.633** (<0.001)	.736** (<0.001)	.634** (<0.001)	.670** (<0.001)
TDS (mg/L)						1	.696**(<0.001)	.666**(<0.001)	.734**(<0.001)	.768**(<0.001)	.773**(<0.001)
TSS (mg/L)						.	1	.757** (<0.001)	.695** (<0.001)	.816** (<0.001)	.742** (<0.001)
EC (µS/cm)								1	.630**(<0.001)	.626**(<0.001)	.772*(<0.001)
DO (mg/L)									1	.802**(<0.001)	.778**(<0.001)
BOD (mg/L)										1	.794**(<0.001)
COD(mg/L)											1

4. Conclusion

Although the physicochemical parameters were below acceptable limits (WHO, 2015; NIS, 2007), Cu and Ni were absent, and Zn levels were within permissible limits. However, Pb and Cd levels exceeded the limits. Water quality indices (HPI, PI, MI) confirmed significant heavy metal pollution in borehole water samples in and around a tertiary institution in Akoka, Lagos, Nigeria. This indicates that the water is unsafe for consumption and domestic use. Additionally, the study showed the need to neutralize the borehole water, which is mostly consumed for drinking, due to its acidic nature.

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