

Impact assessment of cement manufacturing plant on groundwater quality in Ewekoro Community, Ogun State

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ABSTRACT: Cement manufacturing and industrialisation contribute significantly to the economic growth of nations, especially in Nigeria. However, industrial activities have been reported to be a severe source of pollution; hence, proper environmental monitoring must be ensured to control the adverse impacts of cement manufacturing activities for a sustainable ecosystem. This study investigated the effects of the Lafarge Cement Plant on the physicochemical properties and trace metal load in groundwater in the surrounding area. Twenty (20) underground water samples were obtained from different hand dug wells over twenty-four months around the cement factory, and investigated for quality parameters including pH, total dissolved solids (TDS), electrical conductivity (EC), total alkalinity, total acidity, total hardness, anions: sulphate (SO₄²⁻), chloride (Cl⁻), phosphate (PO₄³⁻), and nitrate (NO₃⁻) as well as cations: nickel, cadmium, lead, copper, iron, zinc, calcium, sodium and potassium. Various statistical analyses were also carried out. All quality parameters analysed in the dry season were within the World Health Organisation (WHO) allowable limits, while Fe, Cd, and Pb have concentrations above the WHO acceptable limits. Piper analysis reveal hydrochemical facies of Mg²⁺ - SO₄²⁻, Na⁺ - Cl⁻ and Na⁺ - HCO₃⁻. These results indicate possible groundwater pollution, which may pose a health risk. Hence, there is a need for regular monitoring of groundwater pollution so as to ensure health safety and environmental sustainability, in line with goals 3, 6 and 11 in the Sustainable Development Goals.

Keywords: Cement plant, Ewekoro, groundwater quality parameters, piper analysis, Sustainable Development Goals.

INTRODUCTION

Groundwater is a primary source of water supply globally, supporting agricultural, domestic, and industrial needs (Sana Khalid *et al.*, 2020). The sustainability of groundwater is important to the health, well-being and livelihood of man, especially communities where surface water is limited or heavily polluted (Li *et al.*, 2022). However, industrial activities can be a threat to groundwater quality, introducing various pollutants that may make it unsafe for drinking and other uses (Devi *et al.*, 2017). One of such activities is the production of cement, which is known to generate a large range of environmental pollutants. These pollutants affects the quality of air, water and land, therefore, affecting plant, animal and man (Egbe *et al.*, 2019). The socio-economic advantage of cement production are enormous, as well as the possible adverse environmental impacts which require constant monitoring.

Cement manufacturing processes release particulates, potentially toxic metals, and other contaminants that can infiltrate surrounding aquifers. These pollutants can alter the physicochemical profile of groundwater, affecting quality variables such as pH, TDS and electrical conductivity. Moreover, the presence of trace metals such as cadmium, lead and chromium pose serious health risks, given their toxicity and persistence in the environment (Jafari *et al.*, 2019). There are many factors that could combine to affect the state of the environment, and ultimately, the health of individuals and communities. (Samaila *et al.*, 2021). In addition to the devastating effects on the environment, studies have documented the effects of pollution from cement production on human health (Kolo *et al.*, 2018; Jafari *et al.*, 2019). Several diseases conditions such as respiratory diseases, central nervous

system breakdown, cardiovascular diseases, skin infections and possible cancer, have been associated with pollutants from cement production (Etim *et al.*, 2019; Majolagbe *et al.*, 2018).

Some studies reported the impacts of cement production activities on immediate communities (water, air and soil) (Kolo *et al.*, 2018; Egbe *et al.*, 2019; Laniyan and Adewumi, 2020.) These studies identified and evaluated the sources of environmental pollution and linked the impacts with the health of residents (Purnamasari *et al.*, 2018; Yang, 2020; Shetty *et al.*, 2023; Rauf *et al.*, 2021; Moronkola *et al.*, 2021; Jafari *et al.*, 2019). However, most of these studies around the Lafarge cement factory at Ewekoro collected samples in one season, thus providing a justification for this research which collected groundwater samples in both dry and wet seasons over twenty four (24) months.

This study, therefore, assessed the impacts of Lafarge Ewekoro Cement Plant on the physicochemical properties and trace metal pollution levels of the surrounding groundwater, generating comprehensive data needed for policies and strategies by relevant environmental and health agencies for the safety of lives, and sustainability of the environment in line with goals 3, 6 and 11 of the Sustainable Development Goals (SDGs).

MATERIALS AND METHODS

Study area

Lafarge Africa Cement Manufacturing Plant is situated in the Ewekoro Local Government Area of Ogun State, Nigeria. The local government (LGA) area is bound in the North by Abeokuta north LG, in the East by Obafemi – Owode LG, in the West by Yewa South LG and in the South by Ado-Odo/Ota LG as shown in Figure 1 (Map of the Ewekoro and environ showing sampling locations). Ewekoro is located on latitude 6° 56'N and longitude 3° 13'E. It is about 64 kilometers north of Lagos State and 42 kilometers south of Abeokuta town. Ewekoro is largely rural, with the inhabitants predominantly farmers engaged in farming of sugarcane, cassava, maize and vegetables.

Sampling

Underground water samples for this study were collected from twenty (20) hand-dug wells in the vicinity of the cement factory in Ewekoro, and a Global Positioning System (GPS) was employed to record longitude and latitude of the locations. Pre-washed 1.5 L and 0.75 L plastic bottles were used to collect water samples for physicochemical and trace metal analysis respectively. The samples were taken to the laboratory, preserved at 4°C.

Sample analyses

The pH, temperature, total dissolved solids (TDS), and

electrical conductivity of the water samples were determined *in situ* using hand-held meters, including a pH meter, thermometer, TDS meter and electrical conductivity meter, respectively. Other physicochemical parameters (total hardness, acidity, alkalinity) were determined titrimetrically, chloride by argentometric method, and phosphate was determined using the colourimetric method. Similarly, nitrate and sulphate concentrations were evaluated by spectrophotometric screening and turbidimetric methods, respectively. Cations such as copper, nickel, zinc, cadmium, iron, lead, calcium, sodium, and potassium were determined by the acid digestion method, and quantification was done with a Flame Atomic Absorption Spectrophotometer (FAAS). All parameters were analysed using standard procedures according to APHA/AWWA/WPCF (2022).

Data analyses

Analysis and interpretation of the data generated were carried out using Statistical Package for Social Sciences (SPSS) 20. Descriptive Analysis, Correlation Coefficient, performed through a pair-wise fashion using Pearson Correlation Coefficient; Principal Component Analysis (PCA); and Cluster Analysis (CA) were carried out. A Piper diagram was also plotted with a GW Chart. Correlation Coefficient helps in relating variables with one another in terms of possible sources of pollutants in a particular environmental medium, while Principal Component Analysis elucidate more on various components comprising factors that influence the quality of the environmental medium under investigation. Cluster Analysis is a statistical tool that helps group components of the environmental medium with similar characteristics. The extent to which the water quality parameters exceeded respective WHO acceptable limits was expressed as the exceedance level. It is a unit-less concept, mathematically expressed as:

$$\text{Exceedance} = \frac{\text{Concentration of a quality parameter}}{\text{WHO Limit}}$$

RESULTS AND DISCUSSION

Descriptive statistics of physicochemical quality parameters and trace metals investigated in the underground water of this study in dry and rainy seasons are presented in Tables 1 and 2. Physicochemical quality parameters can be conveniently subdivided into physical parameters, anions and cations (trace metals).

Physical parameters

pH

pH is a measure of the acidity and alkalinity of a solution. Table 1 reveals that the pH of the water samples collected

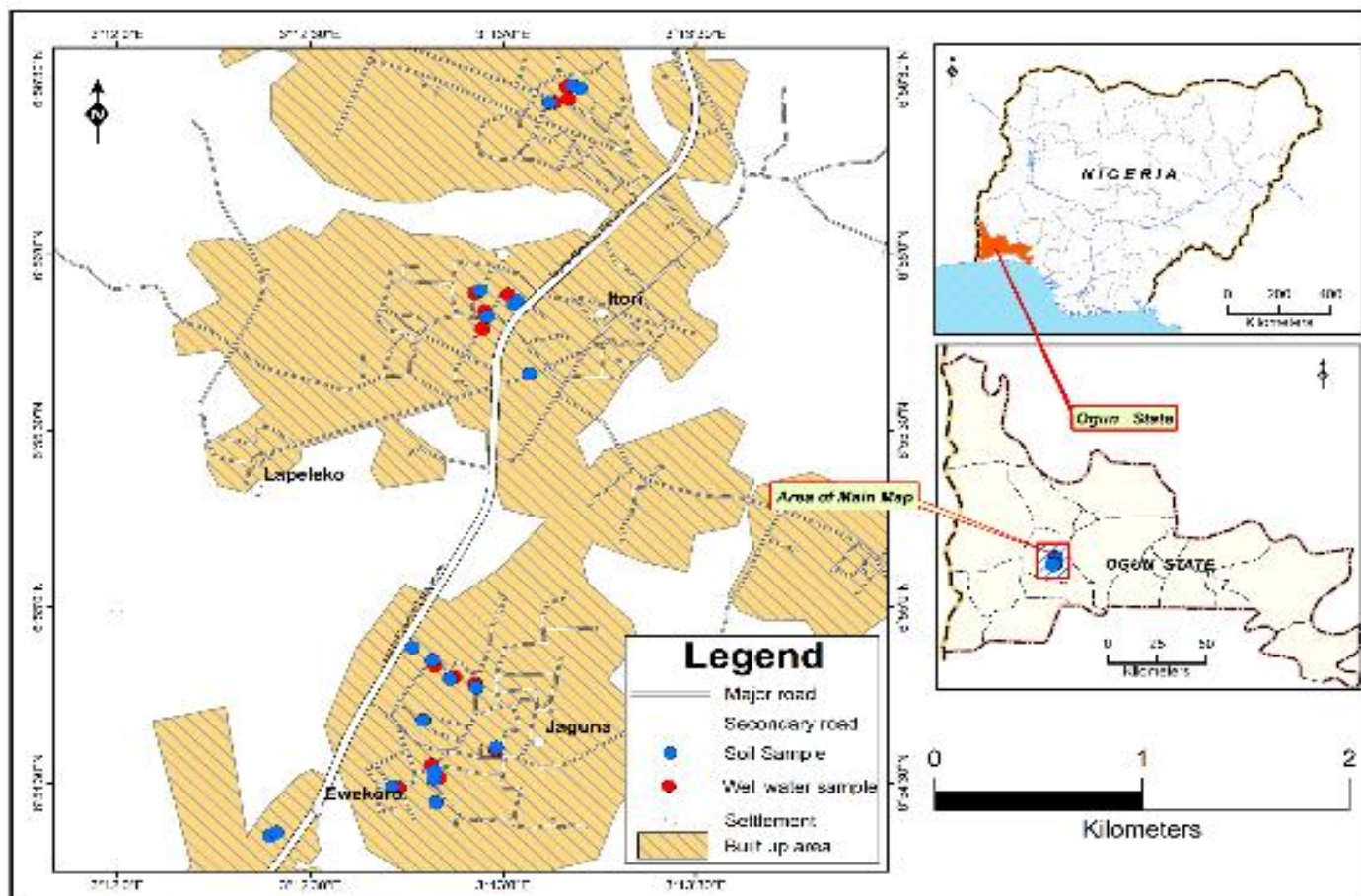


Figure 1. Map of Ewekoro and environs showing sampling points.

Table 1. Physico-chemical and metal analysis data for Ewekoro – Dry Season.

Parameters	Min	Max	Mean	SEM	SD	CV%	% Exceedance	WHO 2000	NSDWQ 2007
pH	6.20	7.30	6.57	0.08	0.35	5.33	0.88	6.5 – 8.5	6.5 – 8.5
Temp (°C)	28.60	31.90	29.85	0.14	0.64	2.14		Ambient	Nil
EC (µs/cm)	38.00	814.00	349.50	43.13	192.89	55.19	0.29	1200	1000
TDS (mg/L)	19.00	407.00	174.75	21.57	96.44	55.19	0.17	1000	500
ALK (mg/L)	12.00	272.75	122.51	18.17	81.28	66.35	1.25	250	Nil
ACD (mg/L)	2.80	96.10	27.28	6.01	26.85	98.53	0.11	250	Nil
TH (mg/L)	30.40	270.60	169.05	15.86	70.92	41.95	0.34	500	150
Cl ⁻ (mg/L)	9.50	165.93	58.18	10.01	44.78	76.96	0.23	250	250
NO ₃ ⁻ (mg/L)	0.15	36.00	7.66	1.94	8.68	113.31	0.15	10	10
SO ₄ ²⁻ (mg/L)	3.27	395.00	116.03	23.96	107.3	93.27	0/46	250	100
PO ₄ ³⁻ (mg/L)	0.03	2.39	0.74	0.15	0.65	87.83	0.15	5	Nil
Fe ⁺ (mg/L)	0.00	1.63	0.21	0.09	0.39	185.72	0.7	0.3	0.3
Cd ⁻ (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.003	0.003
Cu ⁻ (mg/L)	0.00	0.01	0.00	0.00	0.00	0.00	0.00	2	1
Pb ⁻ (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
Zn ⁻ (mg/L)	0.00	0.27	0.10	0.01	0.06	60.00	0.03	3	3
Ca ⁻ (mg/L)	0.73	98.60	27.85	7.11	31.78	114.11	0.37	75	150
K (mg/L)	1.82	50.05	9.37	3.09	13.81	147.39	0.78		Nil
Na (mg/L)	2.79	82.77	27.71	4.66	20.84	75.21	0.14	200	200

Table 2. Physico-chemical and metal analysis data for Ewekoro – Wet Season.

Parameters	Min	Max	Mean	SEM	SD	CV%	% Exceedance	WHO 2000	NSDWQ 2007
pH	4.77	7.47	6.37	0.18	0.84	13.29	0.85	6.5 – 8.5	6.5 – 8.5
Temp. (°C)	28.40	29.30	28.76	0.05	0.24	0.85		Ambient	
EC (µs/cm)	56.00	1877.00	659.05	109.38	489.17	74.23	0.55	1200	1000
TDS (mg/L)	29.00	935.00	329.55	54.60	244.21	74.11	0.33	1000	500
ALK (mg/L)	12.60	112.00	42.99	7.66	34.26	79.70	0.43	250	
ACD (mg/L)	14.00	66.60	32.49	2.80	12.55	38.62	0.13	250	
TH (mg/L)	2.85	23.20	15.17	1.62	7.27	47.92	0.03	500	150
Cl ⁻ (mg/L)	4.40	28.00	13.82	1.63	7.31	52.89	0.06	250	250
SO ₄ ²⁻ (mg/L)	6.46	347.56	76.74	21.52	96.25	125.42	0.31	250	100
PO ₄ ³⁻ (mg/L)	0.43	1.21	0.93	0.05	0.24	25.79	0.19	5	
NO ₃ ⁻ (mg/L)	5.01	29.03	16.99	1.98	8.86	52.17	0.34	10	10
Fe (mg/L)	0.00	2.03	0.39	0.11	0.50	128.72	1.3	0.3	0.3
Cd (mg/L)	0.00	0.05	0.01	0.002	0.01	318.25	1.33	0.003	0.003
Cu (mg/L)	0.00	0.06	0.02	0.004	0.02	119.29	0.01	2	1
Pb (mg/L)	0.00	0.18	0.03	0.01	0.05	193.38	3.05	0.001	0.01
Zn (mg/L)	0.00	0.16	0.04	0.01	0.05	104.76	0.02	3	3
Ca (mg/L)	1.58	131.00	47.25	9.22	41.23	87.27		Nil	150
K (mg/L)	0.90	42.30	11.27	3.39	15.14	1.060	1.189		
Na (mg/L)	5.67	134.46	40.66	8.27	37.01	91.03	0.20	200	200

in the dry season ranged between 6.20 and 7.30. The pH of most of the water samples was within the allowable limits; however, about 45% of the water samples in the dry period were slightly below the WHO permissible limit of 6.5–8.5. Table 2 shows that the pH of the water samples obtained in the wet season was between 4.77 and 7.47, with 50% of the samples having pH values below the WHO allowable limits. This indicates that the pH values of some water samples in the wet season were acidic, and this might have occurred possibly as a result of the reflection of high levels of CO₂ in the atmosphere, leading to acidic rain, and consequently, the phenomenon (Adegbola and Majolagbe, 2019; Onwordi *et al.*, 2022). Some biochemical processes including nitrification, Organic matter decomposition, sulphate reduction and denitrification can leach into groundwater thereby affecting the pH of the aquatic environment. The concentration of acidity in the groundwater is of great health concern to the people in the vicinity of the factory, as it could cause gastrointestinal issues, intestinal proliferations, ulcer and diarrhoea (Orebiyi *et al.*, 2010; Ojekunle *et al.*, 2020; Adeyemi and Ojekunle, 2021).

Electrical conductivity

(EC) is the capacity of water to conduct electricity, reflecting the ionic concentration of a water body (Popoola *et al.*, 2019). Tables 1 and 2 show the EC values in the study, ranging from 38.00 to 814.00 µS/cm for all the water samples in the dry season, and 56.00 to 1880.00 µS/cm

for the wet season. This shows that the samples collected in the dry season were all below the NSDWQ allowable limit of 1000 µS/cm; however, some samples drawn in the wet season were above permissible limits. The higher EC values in the wet season could be due to the dissolution of more ions from industrial activities, which find their way into water bodies through leaching during the wet season (Popoola *et al.*, 2019). The high EC could not lead to corrosion of water nor toxic substances, though may indicate a potential issue.

Total dissolved solids (TDS)

TDS is the water quality parameter which describes the total mineral nutrients in a water body. The water samples investigated in the dry period ranged from 19 to 407 mg/L, and 29 to 935 mg/L for the wet season, showing higher TDS values in the wet season. However, all the results were within the WHO allowable level of 1000 mg/L, but some samples were above 500 mg/L, the limit set by the Nigerian Standard for Drinking Water Quality (NSDWQ).

Total hardness (TH)

TH is an important water quality parameter, which measures how much calcium and magnesium ions are present in a water body. The levels of total hardness of the entire water samples in both wet and dry seasons (Tables 1 and 2) were within the WHO value of 500mg/L, with dry

season values ranging between 30.40 to 270.60mg/L, and 2.85 to 23.20 mg/L for the wet season.

Anions

Chloride could occur naturally in the form of potassium and sodium salts. The level of chloride from this study ranged between 9.50 and 165.93 mg/L with a mean value of 58.2 ± 44 for the dry season, and 4.4 to 28.00 mg/L with a mean value of 13.83 ± 7.31 for the wet season. The lower concentration of chloride observed in the wet season as compared to the dry period is probably as a result of large dilution in the rainy season. All the chloride results from the research study were below the WHO and NSDWQ permissible limit of 250 mg/L.

Sulphate ions occur in water with no known health threat except when in excessive levels. The concentration of sulphate observed in this study ranged from 3.27 to 395 mg/L, with a mean value of 116.0 ± 12 mg/L in the dry season samples, and 6.46 to 347.56 mg/L with mean value of 76.8 ± 96 for the wet season samples (Tables 1 and 2), with about 10% of the results observed above WHO and NSDWQ permissible values of 250 and 100 mg/L respectively. The accumulation of sulphate in water may lead to a disease condition, known as acidosis (Adeyemi and Ojekunle, 2021).

The results obtained for phosphate in this study showed values ranging from 0.03 to 2.39 mg/L, with a mean value of 0.74 ± 0.7 in the dry season, and a range of 0.43 to 1.21 mg/L, with a mean value of 0.94 ± 0.2 for samples collected in the wet season. All the phosphate values observed were within the WHO allowable limit of 5 mg/L (Majolagbe *et al.*, 2023).

The nitrate content in this research study showed concentrations ranging from 0.15 to 36.00 mg/L for dry season samples, while wet samples had values ranging from 5.01 to 29.03 mg/L, as presented in Tables 1 and 2. Most of the concentrations observed were below the WHO permissible value of 10 mg/L. However, 25% of the samples drawn in the dry season and 60% of the samples collected in the wet season had nitrate levels above the allowable limit. The nitrate content could be considered high, and be attributed to application of chemical s and fertilisers in Agricultural activities around the cement factory. Sixty per cent in the wet season is significant and of health consequence. Nitrate has been implicated in a disease condition known as blue baby syndrome (Knobeloch *et al.*, 2000)

Cations

Iron occurs in its natural form as ores in rocks, soil and minerals, constituting a part of the earth's crust. The trace metal is classified as an essential metal playing a vital role in the body's haemoglobin chemistry and human health

(Attar 2020). The value obtained for iron, as shown in Tables 1 and 2 for water samples drawn in the dry season, ranged between 0.00 and 1.63 mg/L with a mean value of 0.21 ± 0.39 , and 0.00 to 2.03 mg/L for wet season samples with a mean value of 0.39 ± 0.50 . However, 20% of the samples in the dry season and 35% of the samples in the wet season had values that were above the permissible level of 0.3 mg/L. Iron cirrhosis is a disease condition reported to be caused by high levels of iron in the human body (Manrai *et al.*, 2022).

Cadmium results obtained from water samples drawn in the wet season had a maximum value of 0.05 mg/L with a mean value of 0.040 ± 0.013 , while there was no trace of cadmium in the samples drawn in the dry season, as presented in Tables 1 and 2. Out of the examined samples from 40 hand-dug wells, only two samples drawn in the wet season showed the presence of Cd, with one having 0.03 mg/L and the other 0.05 mg/L. Cd concentrations were therefore within the WHO and NSDWQ permissible limit of 0.003 mg/L, except for the two samples. High levels of Cd are implicated in premature birth and cancer in humans (Adeyemi *et al.*, 2021). The source of cadmium in groundwater could be traced to Phosphate chemicals and phosphate rocks application to leachate when in contact with soil, i.e., when contaminated with discharges from exploration of limestone for cement manufacturing.

The values of copper as presented in Tables 1 and 2 show a range of 0.00 to 0.01 mg/L for samples obtained in the dry season, and 0.00 to 0.06 mg/L for wet season samples. All the values obtained for Cu across the two seasons were below the NSDWQ and WHO permissible levels of 1 mg/L and 2 mg/L, respectively. Copper can be found in groundwater due to agricultural run-offs, geochemical composition of the soils, etc, and its presence in higher concentrations in water (above the permissible limit) could lead to gastrointestinal disorders after chronic exposure (Majolagbe *et al.*, 2023).

The water samples collected in the dry season and analysed showed no trace of Lead. However, water obtained in the wet season indicated the presence of Lead ranging between 0.00 and 0.18 mg/L and mean values of 0.03 ± 0.06 mg/L, with five samples out of the total of forty samples drawn across the two seasons containing traces of Pb with concentrations above the WHO and NSDWQ permissible limit of 0.001 mg/L. The presence of Lead could be suggested as possibly from the lead-rich waste effluents discharged from a nearby paint industry deposited in the soil which could via leaching find its way into the groundwater even in small concentrations could be toxic and harmful, with the tendency to continuously increase in body tissue posing threat to human health, including interference with Vitamin D and calcium metabolism, brain development hindrance in fetus and children etc (Arshad *et al.*, 2022).

Zinc is an essential element commonly found in the Earth's crust. Zinc metals enter the environment from both natural and human-induced sources. The zinc values for

Table 3. Compares of levels of trace metals in various studies.

Metals	Range (mg/L)	Country	References
Iron	0.009 – 0.581	Turkey	Şener <i>et al.</i> , 2017
	0.0468±0.1403	Turkey	Şener <i>et al.</i> , 2017
	0.232– 0.68	Nigeria	Adeyemi and Ojekunle, 2021
	0.00 – 1.63	Nigeria	This study
Cadmium	0.01 – 0.07	Nigeria	Oluseyi <i>et al.</i> , 2011
	ND – 0.0081	Iraq	Al-Taay <i>et al.</i> , 2018
	ND	Pakistan	Yaqub <i>et al.</i> , 2021
	ND – 0.05	Nigeria	This study
Copper	0.0007 – 0;0341	Turkey	Şener <i>et al.</i> , 2017
	0.0061-0.0345*	Iraq	Al-Taay <i>et al.</i> , 2018
	ND – 0.01	Nigeria	This study
	0.033 – 0.450	Ghana	Adoo <i>et al.</i> , 2013
	0.0817-0.1289	Indonesia	Bandesa at al., 2025
Lead	0.4 – 1.05	Nigeria	Oluseyi <i>et al.</i> , 2011
	0.00 – 0.18	Nigeria	This study
	0.033 – 0.450	Ghana	Adoo <i>et al.</i> , 2013
	0.0001 – 0;0035	Turkey	Şener <i>et al.</i> , 2017
Zinc	0.11 – 0.27	Nigeria	Oluseyi <i>et al.</i> , 2011
	0.0009 – 0.0741	Turkey	Şener <i>et al.</i> , 2017
	0.00628-0.02613*	Iraq	Al-Taay <i>et al.</i> , 2018
	0.014 – 0.5	Nigeria	Adeyemi and Ojekunle, 2021
	ND – 0.27	Nigeria	This study
Calcium	3.9 – 20.1	Nigeria	Ayedun <i>et al.</i> , 2012
	43.12 - 60.15*	Iraq	Al-Taay <i>et al.</i> , 2018
	43.86 – 198.28	Turkey	Şener <i>et al.</i> , 2017
	1.58 – 131.0	Nigeria	This study
Potassium	0.34 – 11.7	Nigeria	Ayedun <i>et al.</i> , 2012
	0.66 – 1.00*	Iraq	Al-Taay <i>et al.</i> , 2018
	0.36 – 28.76	Turkey	Şener <i>et al.</i> , 2017
	1.82 – 50.05	Nigeria	This study
Sodium	7 – 35	Nigeria	Ayedun <i>et al.</i> , 2012
	5.32 – 8.10*	Iraq	Al-Taay <i>et al.</i> , 2018
	1.20 – 25.76	Turkey	Şener <i>et al.</i> , 2017
	5.67 – 134.46		This study

the dry season varied between 0.00 and 0.27 mg/L, with the mean value of 0.10±0.06, and 0.00 to 0.16 mg/L, with a mean value of 0.05±0.05 for the wet season. These values were all below the WHO and NSDWQ permissible limit of 3.0 mg/L. It has, however, been reported that chronic exposure of humans to zinc could lead to cancer (Majolagbe *et al.*, 2023).

Calcium in water could be attributed to the dissolution of

calcite and dolomite in soil. Most calcium in water comes from water run-off from limestone, gypsum, and other calcium-containing rocks and minerals like dolomite (ATSDR, 2009). The value obtained for calcium in this study varied between 0.73 and 98.60 mg/L, with a mean value of 27.85±31.78 mg/L for dry season samples, and a range of 1.58 to 131.00 mg/L with a mean value of 47.25±41.24 mg/L for wet season samples. All the results

Table 4. Correlation analysis for physicochemical and metal data in the Ewekoro groundwater - Dry season.

	pH	Temp	EC	TDS	ALK	ACID	TH	Cl	SO4	PO4	NO3	Fe	Cd	Cu	Pd	Zn	Ca	k	Na
pH	1.0																		
Temp	-.296	1.0																	
EC	-.245	.048	1.0																
TDS	-.245	.048	1.000	1.0															
ALK	-.179	.063	-.094	-.094	1.0														
ACID	-.079	-.162	-.058	-.058	.627	1.0													
TH	-.025	.316	-.180	.380	.380	.310	1.0												
CL	-.042	.635	-.225	-.225	.125	.070	.458	1.0											
SO4	.118	-.096	-.239	-.239	.050	.070	.265	.311	1.0										
PO4	-.079	-.049	-.042	-.042	.354	.114	.007	-.338	-.134	1.0									
NO3	-.237	.161	.005	.005	-.144	-.068	-.120	.214	-.001	-.108	1.0								
Fe	.325	-.055	-.035	-.035	.058	.106	-.018	.168	.127	.268	.153	1.0							
Cd	A	a	a	a	a	a	a	a	a	a	a	a	1.0						
Cu	.222	.053	-.054	-.054	.109	-.126	-.126	.294	.082	.422	.034	.895		1.0					
Pb	A	a	A	a	a	a	a	a	a	a	a	a	a	a	1.0				
Zn	.126	-.188	-.017	-.017	-.180	.025	-.211	-.373	.017	.376	-.072	.206	a	.373	a	1.0			
Ca	.088	-.105	.551	.551	-.113	-.106	-.141	-.240	-.231	.116	.074	.303	a	.255	a	-.273	1.0		
K	-.261	.083	.639	.639	-.085	-.228	-.488	-.195	-.235	-.253	.155	-.179	a	-.142	a	-.131	.424	1.0	
Na	-.412	.083	.772	.772	-.056	.035	-.434	-.303	-.278	-.035	.082	-.199	a	-.050	a	-.198	.243	.824	1.0

obtained were below the NSDWQ allowable limit of 150 mg/L. However, two samples in the dry season recorded 98.60 mg/L and 97.80 mg/L, which are above the WHO allowable limit of 75 mg/L, while 30% of the wet season samples had values above the WHO allowable limits (Atta *et al.*, 2022).

Potassium had values ranging from 1.82 to 50.05 mg/L with a mean value of 9.37 ± 13.81 mg/L for samples drawn in the dry season. Most of the results of analysis for potassium in the samples collected during the dry season were within the WHO allowable limits of 12 mg/L, with only 15% of the samples above the allowable limits. However, 35% of the wet season samples recorded values above the WHO allowable limit (Atta *et al.*, 2022). The result obtained for sodium showed a range of

2.79 to 82.77 mg/L with a mean value of 27.71 ± 20.84 mg/L for samples drawn in the dry season, and 5.67 to 134.46 mg/L with a mean value of 40.66 ± 37.02 mg/L for samples obtained in the wet season. All values observed were within the WHO and NSDWQ permissible limit of 200 mg/L (Brima, 2017; Pandey *et al.*, 2021).

Furthermore, the differences in the concentrations of metals found in groundwater worldwide are highlighted in Table 3. Iron levels in the present study were higher compared with the groundwater samples from other countries' studies, including some studies done in Nigeria. Cd and Cu concentrations in the present study have lower values compared with similar studies done by Oluseyi *et al.* (2011) and Adeyemi and Ojekunle

(2021). Generally, Cd and Cu levels are higher in the present study compared to other related studies done in other countries except for Pakistan. Additionally, the concentration of Pb and Zn is relatively low in the present study when compared to samples analysed from other countries/studies, except studies from Iraq and Turkey. Zn was not detected in samples from Pakistan. Ca level is higher in the present study as compared with studies done in Iraq, but lower than in Turkey (Table 3). K and Na levels are higher in the present study compared with other studies from other countries, as shown in Table 3. It is noteworthy that the levels of all the metals studied are within the WHO and NSDWQ standards for drinking water, except Fe and Pb.

Table 5. Correlation analysis for physicochemical and metal data in the Ewekoro ground water - Wet season

	pH	Temp	EC	TDS	ALK	ACID	TH	Cl	SO4	PO4	NO3	Fe	Cd	Cu	Pd	Zn	Ca	k	Na
pH	1.0																		
Temp	-.296	1.0																	
EC	-.245	.048	1.0																
TDS	-.245	.048	1.000	1.0															
ALK	-.179	.063	-.094	-.094	1.0														
ACID	-.079	-.162	-.058	-.058	.627	1.0													
TH	-.025	.316	-.180	.380	.380	.310	1.0												
CL	-.042	.635	-.225	-.225	.125	.070	.458	1.0											
SO4	.118	-.096	-.239	-.239	.050	.070	.265	.311	1.0										
PO4	-.079	-.049	-.042	-.042	.354	.114	.007	-.338	-.134	1.0									
NO3	-.237	.161	.005	.005	-.144	-.068	-.120	.214	-.001	-.108	1.0								
Fe	.325	-.055	-.035	-.035	.058	.106	-.018	.168	.127	.268	.153	1.0							
Cd	A	a	a	a	a	a	a	a	a	a	a	a	1.0						
Cu	.222	.053	-.054	-.054	.109	-.126	-.126	.294	.082	.422	.034	.895		1.0					
Pb	A	a	A	a	a	a	a	a	a	a	a	a	a	a	1.0				
Zn	.126	-.188	-.017	-.017	-.180	.025	-.211	-.373	.017	.376	-.072	.206	a	.373	a	1.0			
Ca	.088	-.105	.551	.551	-.113	-.106	-.141	-.240	-.231	.116	.074	.303	a	.255	a	-.273	1.0		
K	-.261	.083	.639	.639	-.085	-.228	-.488	-.195	-.235	-.253	.155	-.179	a	-.142	a	-.131	.424	1.0	
Na	-.412	.083	.772	.772	-.056	.035	-.434	-.303	-.278	-.035	.082	-.199	a	-.050	a	-.198	.243	.824	1.0

Further statistical analyses

Correlations coefficient analysis

Correlation coefficient is an important statistical tool, a numerical measure that describe strength and direction of a linear relationship between two variables. It helps predict one variable based on the other. Tables 4 and 5 show the values of Correlations coefficient of all the water quality parameters investigated in groundwater in both dry and wet seasons, respectively. Correlation Analysis (r) reveals existing interaction between continuous variables with values ranging between -1 and $+1$. This statistical tool is used to correlate contaminants in liquid samples. Strong correlation

is said to exist between parameters when $r > 0.7$, while moderate correlation occurs when r ranges between 0.5 and 0.7 . Table 4 presents the Pearson's correlation results of physico-chemical and trace metals in groundwater investigated in the dry season. The results observed showed 28%, 11% and 61% of strong ($r \geq 0.7$), moderate ($0.5 < r < 0.7$) and weak ($r < 0.5$), respectively. Parameters that had strong correlation include: TDS with EC ($r=1.000$) and Na ($r = 0.772$); Cu with Fe ($r=0.895$); EC with Na ($r=0.772$) and K with Na ($r=0.824$). while Table 5 showed parameters sampled for wet season, with 22%, 45% and 33% of the parameters showing strong ($r \geq 0.7$), moderate ($0.5 < r < 0.7$) and weak ($r < 0.5$) correlation, respectively. Strong correlation was observed between TDS and EC (r

$= 1.000$); pH and Alkalinity ($r = 0.823$); EC and SO_4^{2-} ($r=0.747$), as well as TDS and SO_4^{2-} ($r = 0.746$).

Principal components analysis

The principal components analysis (PCA) of the analysis during the dry season as shown in Tables 6 and 7 revealed seven factors/components with a total variance of 84.84%; PC 1 had a total variance of 26.15% with EC, TDS, K, and Na contributing positively. PC 2 had a positive loading for Cl⁻. PC 3 had positive loading for alkalinity and acidity. PC 6 had a positive loading for SO_4^{2-} , while PC 4, 5 and 7 have no parameter with positive contribution.

Table 6. Principal component analysis for physicochemical and metal data in the Ewekoro groundwater - Dry season samples.

Parameters	PC I	PC II	PC III	PC IV	PC V	PC VI	PC VII
pH	-.307	-.490	-.209	.416	-.340	.097	-.153
Temp (oC)	-.028	.688	-.113	.077	.499	-.070	-.384
EC ($\mu\text{s}/\text{cm}$)	.883	.141	.153	.177	-.054	.235	-.178
TDS (mg/L)	.883	.141	.153	.177	-.054	.235	-.178
ALK (mg/L)	-.188	.273	.824	.057	-.062	-.121	.174
ACD (mg/L)	-.200	.150	.728	-.169	-.202	.196	.311
TH (mg/L)	-.519	.451	.353	.261	-.006	.178	-.281
Cl ⁻ (mg/L)	-.419	.758	-.198	.147	.091	.145	-.062
SO ₄ ²⁻ (mg/L)	-.417	.081	-.080	.123	-.121	.714	.181
PO ₄ ³⁻ (mg/L)	-.047	-.403	.594	.020	.511	-.183	-.135
NO ₃ ⁻ (mg/L)	.103	.236	-.286	.123	.513	.015	.680
Fe (mg/L)	-.086	-.428	.028	.659	.404	.184	.084
Zn (mg/L)	.030	-.595	.098	-.369	.411	.420	-.172
Ca (mg/L)	.553	-.068	.191	.697	-.107	-.200	.099
K (mg/L)	.849	.192	-.145	-.041	-.094	-.003	.144
Na (mg/L)	.888	.112	.118	-.285	.079	.209	.015
Eigen Values	4.184	2.444	1.999	1.534	1.321	1.069	1.025
TV%	26.151	15.275	12.491	9.585	8.254	6.683	6.409
CV%	26.151	41.426	53.918	63.503	71.757	78.440	84.849

Table 7. Principal component analysis for physicochemical and metal data in the Ewekoro groundwater - Wet season samples.

Parameters	PC I	PC II	PC III	PC IV	PC V	PC VI
pH	.392	-.428	-.692	-.145	.250	.110
Temp. (oC)	.298	.602	-.261	-.256	-.237	-.482
EC ($\mu\text{s}/\text{cm}$)	.882	-.130	.340	.099	-.074	.146
TDS (mg/L)	.881	-.130	.342	.099	-.074	.146
ALK (mg/L)	.518	-.466	-.588	-.018	-.139	.101
ACD (mg/L)	.199	-.110	.567	-.204	-.622	.236
TH (mg/L)	-.335	-.106	.677	.117	-.006	-.307
Cl ⁻ (mg/L)	.069	.586	.143	-.345	.082	.376
SO ₄ ²⁻ (mg/L)	.909	.197	-.030	.041	-.022	.104
PO ₄ ³⁻ (mg/L)	.022	-.337	.241	-.264	.727	-.190
NO ₃ ⁻ (mg/L)	-.339	.099	.264	-.393	.140	.631
Fe (mg/L)	.590	.409	-.179	.518	-.010	-.103
Cd (mg/L)	.456	.478	.158	-.080	.571	.202
Cu (mg/L)	-.423	.006	-.359	.522	-.173	.536
Pb (mg/L)	.650	.573	-.008	-.114	.031	-.062
Zn (mg/L)	-.148	.223	.130	.866	.324	.115
Ca (mg/L)	.420	-.760	-.074	-.156	.069	.072
Na (mg/L)	.385	-.547	.537	.328	.039	-.102
Eigen Values	4.669	2.977	2.552	1.949	1.560	1.406
TV%	25.941	16.539	14.175	10.827	8.667	7.810
CV%	25.941	42.480	56.656	67.482	76.150	83.960

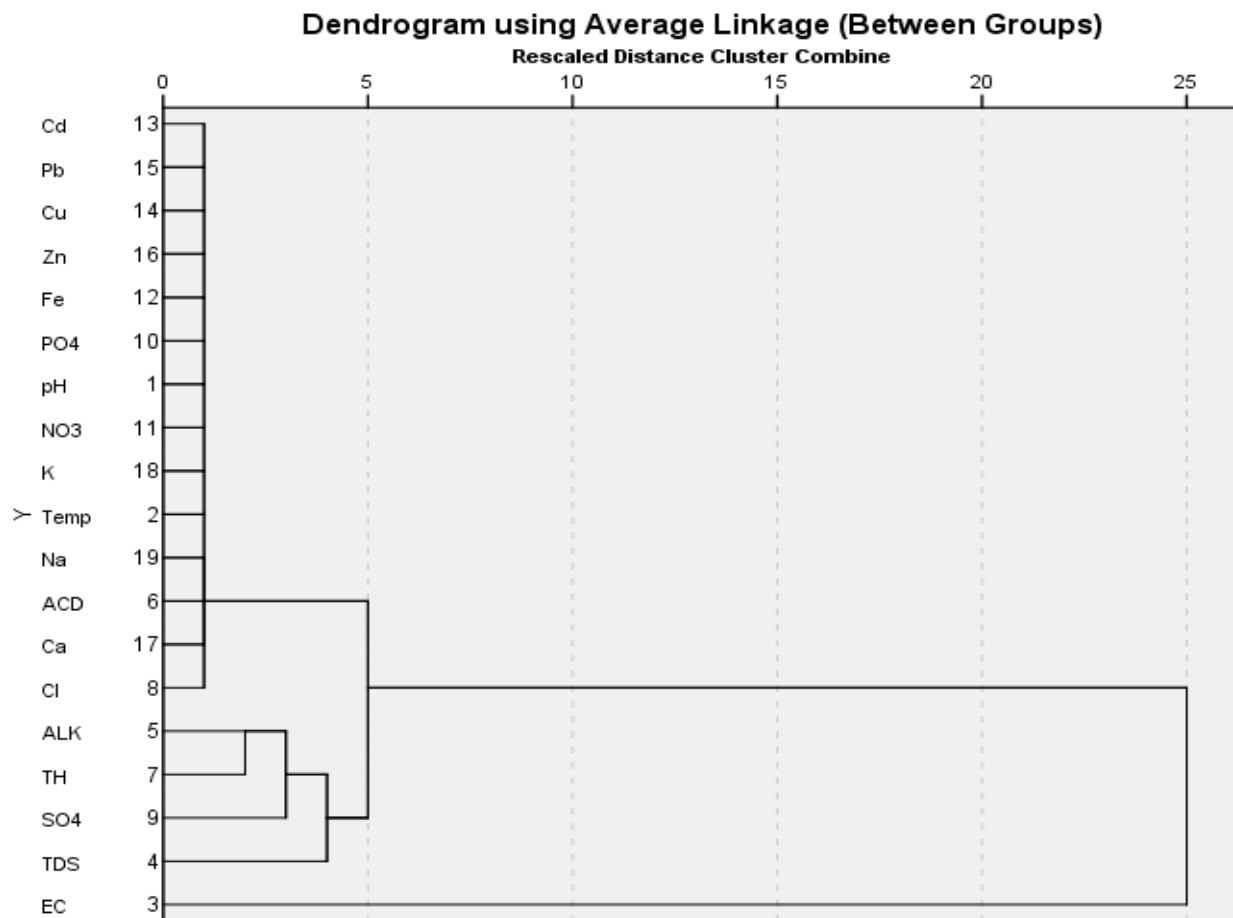


Figure 2. Dendrogram for physicochemical and trace metals in the Ewekoro groundwater - Dry season samples.

Furthermore, groundwater parameters for the wet season were separated into six components by PCA with a total CV of 83.96% variance. PC 1 had a total variance of 25.94%, with EC and TDS having positive contributions. PC 2 to PC 6 had no positive contribution.

Cluster analysis (CA)

Cluster analysis is a statistical technique employed in grouping objects, such as quality parameters or sample locations, into the same structure or hierarchy with similar characteristics. The clustering of water quality parameters in this study in both the dry and wet seasons is shown in Figures 2 and 3, respectively.

The dendrogram (Figure 2) shows five clusters: I, II, III, IV and V. The Cluster I consists of fourteen quality parameters: Cd, Pb, Cu, Zn, Fe, PO_4^{3-} , pH, NO_3^- , K, Temperature, Na, Acidity, Ca and Cl. Cluster II is made up of Alkalinity and Total Hardness, while Cluster III, IV and V are solo parameter clusters of SO_4^{2-} , TDS and Electrical Conductivity, respectively. The dendrogram (Figure 3) also shows five clusters: I consists of five parameters: PO_4^{2-}

, NO_3^- , Fe, Cd and Pb; II consists of Total Hardness and SO_4^{2-} ; III consists of Temperature, Cl, EC, Ca, K, Zn, Acidity, and Cu. IV consists of pH and Na, as well as cluster V, which had only TDS.

Classification of groundwater

Piper diagrams, otherwise called a trainer diagram, are a reliable statistical tool employed in hydrochemistry to classify water into different types or facies. It reveals dominance of ions, thereby classifying water in the aquifer (Chapagain *et al.*, 2010; Raju, 2007). Piper diagram, as shown in Figures 4 and 5, classifies groundwater around the Ewekoro cement plant in both dry and wet seasons, respectively. Naturally, hydrogen carbonate and carbonate are domicile anions, while sodium and potassium are domicile cations in the aquifer, but are in constant competition or an ion exchange process with Cl^- and SO_4^{2-} for anions, as well as Ca^{2+} and Mg^{2+} for cations, indicating possible pollution in the aquifer.

Thus, piper analysis can also help in determining the suitability of water use. The dispersion of sample points in

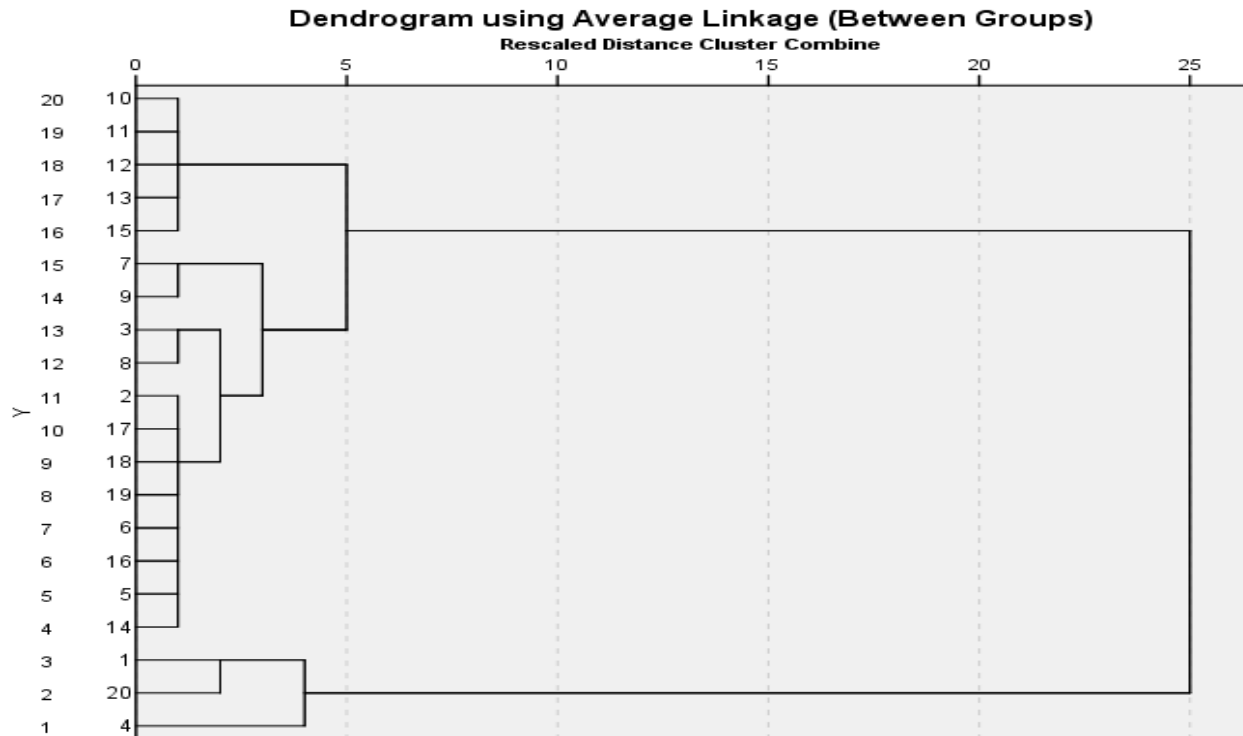


Figure 3. Dendrogram for physicochemical and trace metal in the Ewekoro groundwater - Wet season samples.

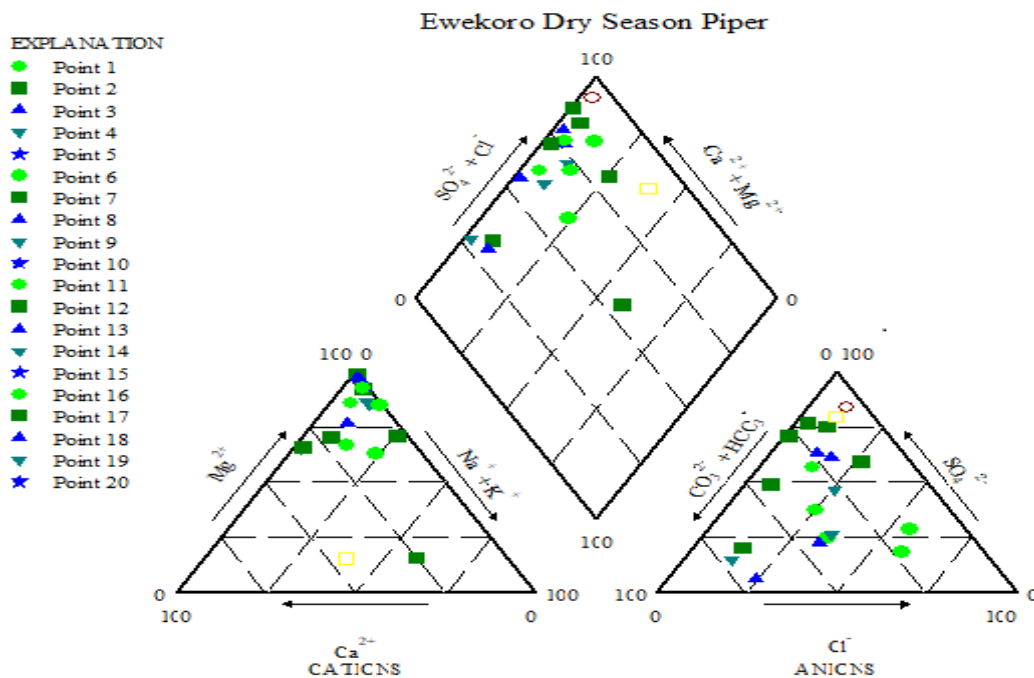


Figure 4. Piper diagram for groundwater in Ewekoro in the dry season.

the piper diagrams (Figures 4 and 5) is very similar except for the effect of dilution in the wet period, hence, more dissolution of minerals. The dominance of SO_4^{2-} and Cl^- in

both seasons, hence, a reflection of ion exchange with the natural components of HCO_3^{2-} and CO_3^{2-} . This indicates a probable anthropogenic effect from cement production

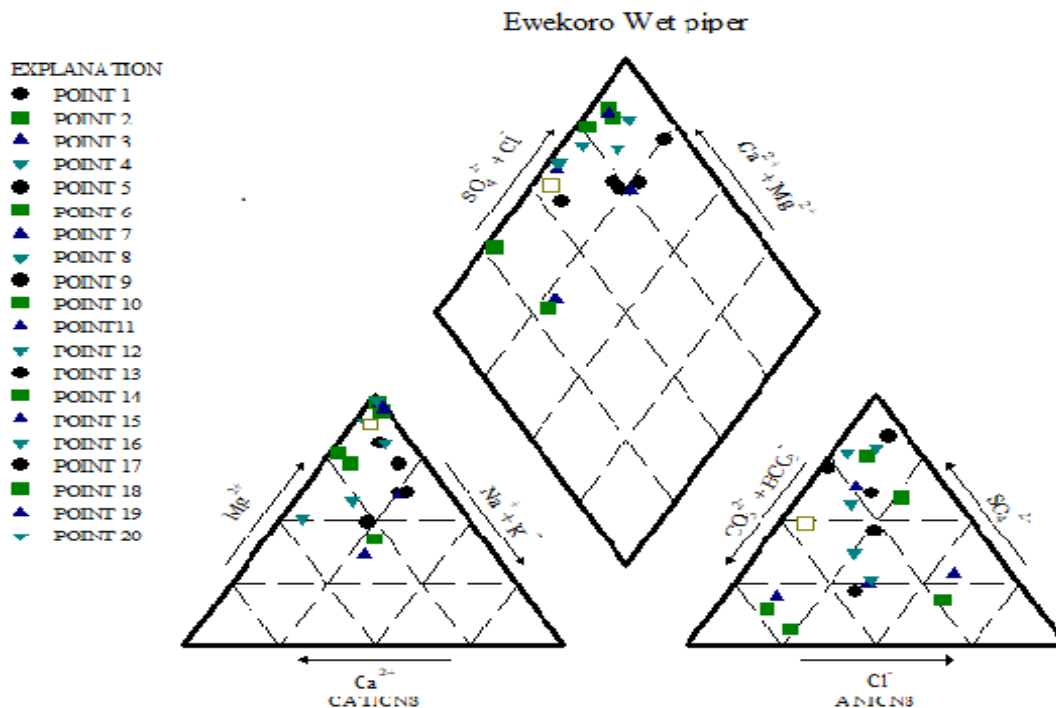


Figure 5. Piper diagram for groundwater in Ewekoro in the wet season.

activities. The presence of chloride pollution shows the unsuitability of the water under investigation for domestic and agricultural purposes. Dominance of Mg^{2+} indicates that the underground water samples investigated in the study area are hard. The piper diagrams in both seasons reflect hydrochemical facies of $Mg^{2+} - SO_4^{2-}$, $Na^+ Cl^-$ as well as $Na HCO_3^-$.

Conclusion

This research work was aimed at carrying out an assessment of the impact of the Lafarge Africa Ewekoro Cement Plant on the physicochemical and trace metal pollution load of the surrounding groundwater. The study examined selected quality parameters such as pH, total dissolved solids (TDS), electrical conductivity (EC), total alkalinity, total acidity, total hardness, phosphate (PO_4^{3-}), chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), copper, nickel, cadmium, iron, lead, zinc, calcium, sodium and potassium. The result of laboratory analysis showed most parameters were within the WHO limits, except for some sample locations, where Cd and Pb, which are above the WHO permissible limits for drinking water, portended health risks, which may be attributed to the impact of the cement plant activities on locations close to the plant. Various statistical analyses were carried out, including Principal Component Analysis, Correlation Coefficient, Exceedance, Correlation Analysis, and Cluster Analysis (CA). Piper diagram was plotted, revealing hydrochemical facies: $Mg^{2+} - SO_4^{2-}$, $Na^+ Cl^-$ as well as $Na HCO_3^-$. Regular

monitoring of groundwater quality status in Ewekoro, the study area, is important, so as to be updated with the buildup of pollutants in the environment, thereby saving lives and ensure sustainable environment in line with the Sustainable Development Goals (SDGs).

The result of laboratory analysis showed most parameters were within the WHO limits, except Cd and Pb, which are above the WHO permissible limits for drinking water, portending health risks, which may be attributed to the impact of the cement plant activities on locations close to the plant.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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