Global Journal of Earth and Environmental Science
Volume 10(1), pages 59-65, February 2025
Article Number: 45E237E06
ISSN: 2636-6002
https://doi.org/10.31248/GJEES2024.181
https://integrityresjournals.org/journal/GJEES

Full Length Research

Physicochemical impact of cement manufacturing industry on groundwater quality in Onigbedu, Ogun State, Nigeria

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Received 25th December 2024; Accepted 3rd February 2025

ABSTRACT: Groundwater is an essential source of water supply around the globe, and it can be affected by anthropogenic activities, leading to several disease conditions, especially in rural areas. Many citizens lack access to potable water, largely due to pollution from industrial and agricultural activities. Cement industries release effluents into water bodies, air and soils, thereby posing serious health risks. This study assessed the quality of groundwater in Onigbedu, Ogun State. Twenty (20) groundwater samples were collected and analyzed for physicochemical parameters such as pH, temperature, alkalinity, total hardness (TH), electrical conductivity (EC), total solids, total dissolved solids (TDS), chloride, sulphate, nitrate, and phosphate using standard procedures. Trace Metals, including Cd, Cu, Fe, Zn, Na, K, Ca, and Pb, were also determined. Multivariate analyses were used to analyze the data generated. Most of the physicochemical parameters and trace metals investigated were found within the World Health Organization (WHO) allowable limits, while some of the sample locations had values of pH, PO_4^{3-} and Fe concentration above the WHO limits, especially in locations having strong correlations with TH (r =0.898), Na (0.801) and Ca (r = 0.820). K also correlated strongly with Ca (r = 0.768). In conclusion, there is a need for water remediation and regular monitoring of groundwater in the study area, to ensure the safety of man and sustainability of the environment in line with Goals 6 and 7 of the Sustainable Development Goals.

Keywords: Cement industries, groundwater, Onigbedu, physicochemical, trace metals.

INTRODUCTION

Groundwater is a major source of water supply globally, especially in Nigeria. In the present times, groundwater resources are of economic importance for playing a vital role in the growth of contemporary societies. Hence, groundwater resource qualitative assessment and its sustainability are of utmost importance to a nation (Lasagna *et al*., 2020). Human involvement with the hydrological system, including the leaking of fertilizers and pesticides beneath agricultural land, can have a significant adverse impact on groundwater quality (Syafrudin *et al*., 2021). Other anthropological factors that compromise groundwater quality include leachate from municipal dumpsites, salt water intrusion, application of agricultural chemicals, oil spillage and pipeline vandalisation and geological formations (Idehen and Uguru, 2021).

Quality issues have been of great interest to environmental researchers in recent decades (Akhtar *et al*., 2021; Li *et al.,* 2021). Although Nigeria is naturally endowed with an abundance of different types of drinking water, including surface, ground, and atmospheric (rainwater).

The country has long been contending with issues related to water sources. The shortage of clean drinking water for about 66.3 million Nigerians is mostly caused by pollution from industrial or mining operations, leakages from landfills, salt water intrusion (Adamu *et al*., 2022; Majolagbe *et al*., 2023), oil exploration, agriculture, and the production of cement, among other sources (Omole and Isiorho, 2011).

In Nigeria, groundwater has been found very important in various uses, including industrial, agricultural and domestic services. United Nations Children's Fund and World Health Organization (UNICEF/WHO) in 2018 through Joint Monitoring Programme (JMP) for Water Supply and Sanitation and Hygiene established that 60% of total global population were relying on groundwater as the main source of drinking water: 73% in rural areas and 45% in urban areas. However, the water supply for the towns of Calabar and Port Harcourt is entirely derived from groundwater (JMP, 2019).

Human activities such as the discharge of sewage and untreated wastewater release a large number of pollutants into the water. The growing process of global water contamination is a serious risk to the environment. (Shah and Patel, 2011). The inefficient legislation guiding waste disposal practices is a problem in the handling of municipal solid wastes (Abubakar *et al*., 2022). Mineral ions are naturally present in groundwater. These ions gradually dissolve from soil particles, sediments, and rocks when water moves along mineral surfaces in the pores or fractures of the unsaturated zone and aquifer. They are referred to as dissolved solids. Some dissolved solids may have originated in the precipitation of water or river water that recharges the aquifer. The dissolved constituents, termed total dissolved solids (TDS), constitute positively charged ions (cations) and negatively charged ions (anions). Except for organic matter derived from top soils, all naturally occurring dissolved solids are inorganic, such as trace elements, including metals. Trace elements are typically found in very low amounts and consequently pose no risk to human health. Numerous trace elements are considered important for human metabolism, while high concentrations of trace metals can also be found in groundwater near contaminated sources, consequently posing health threats (Jaishankar *et al*., 2014; Gu *et al*., 2020)

The rise in demand for groundwater resources leading to groundwater overexploitation in the last few decades is tagged "silent revolution," with millions of farmers investing their private capital in drilling and pumping technologies and operating without the approval of formal water bureaucracies. (Omole and Isiorho, 2011). The over abstraction of groundwater often causes an increase in pollutants in an area, particularly an area not too far from aquatic regions. Some trace metals that are associated with industrial pollution, including arsenic and chromium, may occur in groundwater at concentrations that are high enough to make that water unsuitable for drinking purposes (Adeniran *et al*., 2019). Cement is an adhesive widely used in the building industry. It is used on roads, residences, bridges, commercial and residential buildings; consequently, the cement manufacturing industry plays a vital role in the global economy. Rapid infrastructure, urbanization, and the need to increase domestic product output constitute the primary drivers of the growth in cement production (Oni *et al.,* 2017). The abundance of raw materials in Nigeria has prompted a surge in indigenous production, with an annual cement production surge by more than 1300% between 1990 and 2013, from less than 2 million tons to over 28 million tons (Ighalo and Adeniyi, 2020).

Water contamination from cement manufacture in Nigeria has allowed poisons to accumulate in the tissues of aquatic life, posing a health danger to human consumers. Polluted water has been connected to a steady pandemic of water-borne diseases in Nigeria in recent years, including diarrhea, dysentery, cholera, and gastroenteritis (Botting, 2010). The quantities of specific parameters can be used to determine groundwater quality. Knowledge of how these materials vary spatially also influences underground flow patterns (Kasvi *et al.,* 2017).

Raw materials employed in cement manufacturing include iron ore, limestone, shells, and chalks or marl combined with shale, clay, slate, blast furnace slag, and silica sand. Cement also contains trace elements such as nickel (Ni), cobalt (Co), cadmium (Cd), copper (Cu), zinc (Zn), chromium (Cr), arsenic (As), and lead (Pb), which may be harmful contaminants in groundwater. Therefore, this research study was designed to assess the effect of cement industries' activities on the quality of groundwater in Onigbedu, Ogun State.

METHODOLOGY

Study area

Onigbedu town is in Ewekoro Local Government, Ogun State, with longitude 6.9333˚N and latitude 3.167°E. The town has a significant population with residents mainly engaged in farming, particularly in Sugar cane plantation, trading and craftsmanship. The town plays host to a cement manufacturing plant, the only major industry. The map showing sampling locations is shown in Figure 1.

Sample collection

Twenty (20) groundwater samples were collected from ten (10) different hand dug wells for physiochemical and trace metal analyses in December 2023. The plastic bottles used were subjected to standard washing protocols and used to collect water samples for physicochemical and metal analysis. The 1.5 L bottles were preserved by filling to the brim to avoid microbial degradation for water

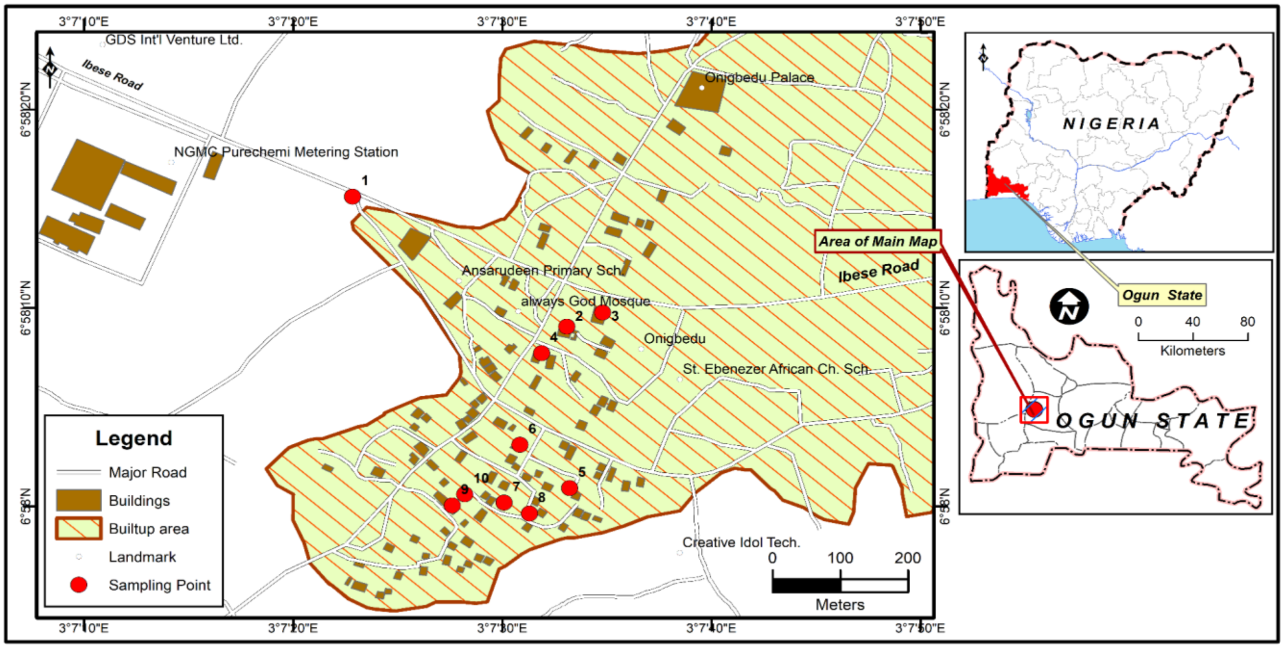

Figure 1. Map showing sample locations.

samples for physicochemical, while the 0.75 L plastic bottles were filled with water samples (for metal analysis), preserved by adding 1mL of nitric acid, and the samples were taken to the laboratory for analysis.

Hydrochemical analyses

Various quality parameters investigated in the groundwater samples collected include electrical conductivity (EC), pH and temperature. EC and pH were measured employing a conductivity meter (Mettler Toledo) and pH meter (pHep HANNA HI 98107), respectively, while temperature was measured using a mercury bulb thermometer. Acidity and alkalinity were determined titrimetrically, total hardness by complexometry, while total suspended solids (TSS) and total dissolved solids (TDS) were estimated by gravimetry. Anions investigated chloride by the silver nitrate method, sulphate by turbidimetry, phosphate by colorimetric and nitrate by the phenol disulphonic acid method. Determination of cations Na+, and K+ and trace metals were done with a flame photometer and Flame Atomic Absorption Spectrophotometry (Buck scientific 210V model), respectively, after acid digestion of the samples. Each sample analyzed was duplicated to ascertain the validity of the method.

Statistical data analyses

Descriptive analyses of data generated from the laboratory exercise were carried out using Statistical Package for Social Sciences (SPSS) 20. Correlation coefficient was performed in a pairwise fashion through the Pearson correlation coefficient. Principal component analysis (PCA) was also performed to determine the association between parameters. The degree by which some of the groundwater parameters exceed their respective WHO allowable limit is expressed as exceedance. It is a unitless concept, expressed mathematically in Eq.1

$$\text{Exceedance level} = \frac{\textit{Concentration of quality parameter}}{\textit{WHO accaptable limit}} \qquad (1)$$

RESULTS AND DISCUSSION

The descriptive analysis of concentrations of physicochemical quality parameters and metallic concentration in the groundwater samples investigated in Onigbedu is shown in Table 2, and the correlation coefficients amongst varying quality parameters are displayed in Table 1.

Most of the physicochemical and metal parameters had values within the World Health Organisation (WHO) standards and allowable ranges, except pH, phosphate, and Fe. pH had a mean value of 7.75, within the WHO allowable range of 6.5 - 8.5. About 20% of the water samples analyzed exceeded the WHO limits (WHO, 2013). This showed that some of the locations had high alkaline pH water. This could be caused by both natural factors such as the geologic nature of the study site, mineral deposits and possible characteristics that results from processes of weathering releasing alkaline ions. An inverse relationship was observed between the depth of the wells and the pH values, implicating the carbonate

Table 1. Correlation analysis of groundwater samples in Onigbedu, Ogun State.

	pH	Tem	EC	TDS	Alk	Acd	TS	TH	Cl	SO_4^{2-}	PO_4^{3-}	NO_3^{2-}	Cd	Cu	Fe	Zn	Na	K	Ca	Pb
pH	1																			
Temp	.004	1																		
EC	-.099	-.280	1																	
TDS	-.231	-.326	**.935**	**1**																
Alkal	**.677***	.577	-.423	-.543	1															
Acid	.388	-.278	.121	.164	-.038	1														
TS	-.290	-.324	.319	.413	-.404	-.360	1													
TH	-.184	-.155	**.882****	**.898****	-.278	.112	.269	1												
Cl	.224	-.314	.150	.243	-.120	**.936****	-.297	.153	1											
Sulph	-.082	**-.815**	**.638***	.703*	**-.747***	.408	.265	.470	.416	1										
Phos	-.382	-.552	-.075	.137	**-.761***	.046	.285	-.191	.080	.594	1									
Nitrat	.284	.374	-.390	-.640*	.523	-.464	-.336	-.457	-.646*	-.575	-.426	1								
Cd	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}							
Cu	.408	.172	.276	.105	.106	-.207	.107	-.085	-.326	.042	-.075	.374	.^{b}	1						
Fe	-.316	.399	-.140	-.043	-.008	-.109	-.350	-.028	.022	-.177	.104	-.226	.^{b}	-.260	1					
Zn	-.289	.076	.148	.272	-.297	-.141	.028	.142	-.032	.220	.402	-.413	.^{b}	-.028	**.850****	1				
Na	-.108	-.263	**.676***	**.801****	-.336	.233	.030	.703*	.388	.564	.126	-.604	.^{b}	.004	.084	.233	1			
K	.010	-.397	.494	.695*	-.411	.320	.346	.525	.366	.690*	.478	**-.784**	.^{b}	-.048	.236	.604	.598	1		
Ca	-.263	-.095	.714*	**.820****	-.496	.269	.077	.684*	.368	.591	.248	-.707*	.^{b}	.028	.480	.687*	.723*	**.768****	1	
Pb	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}

N B : ^{b} = Nil.

(CO_3^{2-}) alkalinity sources, which are typically found in areas with alkaline rock or hydrothermal activity (Sánchez-Soberón et al., 2015).

This further reveals the possible impact of high CO_2 production, the situation common in cement manufacturing areas, and human-induced factors, including leachate from landfills and applications of chemicals and fertilizers. However, high alkaline pH in water initiates a bitter taste, and corroded water pipes or appliances become encrusted with deposits, depressing the effectiveness of chlorine disinfection.

High pH has some health benefits, including clearing the human body system of toxins, thereby improving metabolism (Aoi *et al*., 2014). The pH maintains a strong chemical association with total alkalinity (r = 0.677) as shown in Table 2. Total hardness (TH) is another important quality parameter. TH is a result of the existence of divalent metallic cations (Ca^{2+} and Mg^{2+}), and it can be calculated as the sum of Ca^{2+} and Mg^{2+} concentration as meq/L equivalent to $CaCO_3$ (Yang *et al*., 2011). The classification of water based on TH by the Environmental Protection Agency (EPA, 1980), is as tabulated in Table 3. About 60% of the groundwater samples investigated are potable and may not need further water treatment.

The TH has a very strong positive correlation with EC (r = 882) and TDS (r = 898). This reflects possible common sources including geological formation and runoff, hence contribution from dissolved ions including Ca, Mg, sodium and carbonates. The situation may implicate homogenous

Table 2. Descriptive analysis of quality parameters groundwater samples Onigbedu.

Parameters	Min	Max	Mean	SD	SEM	CV%	Exceedance	WHO
pH	6.40	9.10	**7.75**	0.89	0.28	0.12	1.03	**6.5 - 8.5**
Temperature	28.00	33.00	30.10	1.60	0.50	0.05	-	-
EC (µS/cm)	170.00	992.00	588.70	247.12	78.15	0.42	0.42	1400
TDS (mg/L)	64.00	333.00	238.20	93.94	29.71	0.39	0.24	1000
ALK (mg/L)	8.60	50.60	16.60	12.68	4.01	0.76	-	250
ACD (mg/L)	33.40	185.40	63.34	47.02	14.87	0.74	-	-
TS (mg/L)	0.00	0.00	0.00	0.00	0.00	0	-	-
TH (mg/L)	36.00	208.00	137.40	52.03	16.45	0.38	0.27	500
Cl (mg/L)	4.77	125.66	41.20	38.11	12.05	0.93	0.16	250
SO4 (mg/L)	3.61	8.80	7.10	1.49	0.47	0.21	0.03	250
PO4 (mg/L)	6.04	**8.74**	**7.83**	0.86	0.27	0.11	**1.57**	5
NO3 (mg/L)	0.65	4.82	2.25	1.54	0.49	0.68	0.23	10
Cd (mg/L)	0.00	0.00	0.00	0.00	0.00	0	-	-
Cu (mg/L)	0.00	0.02	0.00	0.01	0.00	0	0	250
Fe (mg/L)	0.00	**0.51**	0.11	0.15	0.05	1.36	**0.37**	0.3
Zn (mg/L)	0.00	0.04	0.01	0.01	0.00	0	0.003	3
Na (mg/L)	6.51	86.49	41.76	22.91	7.25	0.55	0.21	200
K (mg/L)	0.00	16.38	8.46	6.11	1.93	0.72	-	-
Ca (mg/L)	4.91	66.02	39.73	19.37	6.12	0.49	-	-
Pb (mg/L)	0.00	0.00	0.00	0.00	0.00	0	0	0.001

Table 3. Classification of groundwater investigated based on total hardness.

Total hardness $CaCO_3$ mg/L	Water classification	Percentage of the wells
< 75	Soft	10
75 – 150	Moderately Hard	50
150 - 300	Hard	40
>300	Very Hard	0

aquifer characteristics such as uniform geology and water flow. Total dissolved solids is another important water quality parameter that effectively defines water. TDS has a very strong chemical association with EC (r = 935). Total dissolved solids also maintain strong correlations with ions: SO_4^2, K, Na, and Ca (r = 703, 695, 801 and 820, respectively).

All these ions, along with TDS, constitute the first principal component (PC1) as shown in Table 4. However, TDS notably has a strong negative chemical association with nitrate (r = -640), indicating differential possible sources of influences.

Phosphate had a 1.57% exceedance of 1.57, with the mean value of 7.83 mg/L, as opposed to the WHO standard limit of 5.0 mg/L. Phosphate can enter waterways from human and animal waste, phosphorus-rich bedrock, laundry and cleaning wastewater, industrial effluents, and fertilizer runoff (Witek-Krowiak *et al*., 2022). Excess phosphate can be toxic, as it can lead to diarrhea and can interfere with the body's ability to use iron, calcium, magnesium, and zinc.

Table 4 showed Principal Component Analysis (PCA) of Groundwater in Onigbedu, Ogun State, revealing five (5) different principal components of water analyzed, with each component revealing varying quality parameters contributing majorly (>0.500) to the group. PCA not only reduce the dimensionality of data, but it also helps identify the most relevant features in the data complexities. PC1, PC2, PC3, PC4 and PC5 made up TDS, EC, TH, SO_4^{2-}, Na, Ca and K; pH, acidity and Cl; Fe; Temperature, and TH; pH and Cu, respectively.

All trace metals investigated in the groundwater samples, including Cd, Cu, Fe, Zn, Na, K, Ca and Pb, were observed below the WHO acceptable limit of drinking water, except Fe. Iron in this study has an exceedance value of 0.3%, with about just 10% of the sampling locations exceeding 0.3 mg/L WHO limit. Iron is easily classified as a nutritive metal, but can become toxic when it exceeds the allowable limit. It has been implicated in a diseased condition known as liver cirrhosis.

Table 4. Principal component analysis of groundwater in Onigbedu, Ogun State.

Parameters	Components				
	PC 1	**PC 2**	**PC 3**	**PC 4**	**PC 5**
pH	-.288	**.709**	.103	.175	**.536**
Temperature	-.522	-.275	.339	**.598**	-.061
EC	**.751**	.166	-.328	.491	-.031
TDS	**.901**	.063	-.225	.353	-.083
Alkalinity	-.707	.320	.273	.428	.076
Acidity	.337	**.723**	.479	-.244	.015
Total solid	.339	-.253	-.675	-.096	-.054
Total hardness	**.713**	.118	-.160	**.539**	-.328
Chloride	.446	**.611**	**.544**	-.253	-.107
Sulphate	**.852**	.203	-.204	-.287	.205
Phosphate	.459	-.360	-.067	-.707	.311
Nitrate	-.834	-.011	-.280	.188	.163
Cu	-.097	.087	-.419	.394	**.723**
Fe	.124	-.617	**.736**	.177	.083
Zn	.455	-.646	.440	.113	.361
Na	**.770**	.157	.067	.308	-.071
K	**.845**	-.031	.154	-.004	.292
Ca	**.870**	-.162	.282	.321	.105
Eigen Values	7.093	2.715	2.507	2.375	1.354
TV%	39.408	15.082	13.927	13.196	7.522
CV%	39.408	54.490	68.417	81.614	89.136

Conclusion

The impact of cement manufacturing activities on groundwater in Onigbedu, Ewekoro Local Government, Ogun State, was investigated. The water alkaline pH observed could probably be from carbonate (CO_3^{2-}) alkalinity sources, which is typically found in areas with alkaline rock, revealing the possible impact of high CO_2 production, a situation common in cement manufacturing areas. About forty percent of the water analyzed is classified as hard water, hence requiring water treatment to be potable. Iron is the only of the eight cations investigated that is above the 0.3 mg/L WHO allowable limit in drinking water. Principal Component Analysis reveals five (5) different components as PC1, PC2, PC3, PC4 and PC5 made up of TDS, EC, TH, SO_4^{2-}, Na, Ca and K; pH, acidity and Cl^-; Fe; temperature, respectively. There is a need for regular monitoring of groundwater quality around the cement factory for possible buildup of contaminants, thereby ensuring the safety of man and sustainability of the environment in line with goals 6 and 11 of the Sustainable Development Goals.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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