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Geochemical Background and Correlation Study of Ground Water Quality in Ebocha-Obrikom of Rivers State, Nigeria

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ABSTRACT

Background and Objective: Pollution in the Niger Delta has resulted in approximately nine million premature deaths, accounting for 16% of global mortality, surpassing AIDS, TB and malaria combined. Pollution-related illness claims one in four lives in the most affected nations. The objective is to determine the relationship between the physicochemical and heavy metals parameters in groundwater in the study area. **Materials and Methods:** Between September, 2019 and August, 2020, the sample was collected. Standardized analytical procedures were used in the study. All sampling, conservation, transportation and analysis were carried out in accordance with the 2018 APHA recommendations. To stop the deterioration of the organic components, all obtained samples were transported to the research lab while being preserved in an icebox. The significance level was set at $p<0.05$. **Results:** It shows that most of the physicochemical indices and heavy metals are correlated significantly with each other during wet and dry seasons. The sign (+) implies that as one parameter of the groundwater increases, the others increase significantly and (-) shows the reverse is the case when one parameter of water increase increases, the other parameters decrease significantly between each of the indices in Ebocha-Obrikom. All the findings were statistically significant ($p<0.001$). **Conclusion:** Groundwater pollution is caused by irresponsible, short-sighted and unsustainable exploitation of oil and gas resources. Evidence-based strategies are needed to address pollution at the source and a linear regression analysis technique is an effective tool for monitoring groundwater. Extensive monitoring is needed to track its development.

KEYWORDS

Regression analysis, correlation, extractive industry, Niger Delta environment, groundwater analysis, blocks of sustainability

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INTRODUCTION

Groundwater can become a vector of organic and inorganic contaminants, compromising the quality of this precious resource and as a result, endangering local people's living conditions. Groundwater can be a constraint (dewatering) or an asset for the extractive industry in terms of quantity (meeting the needs of the people). Using groundwater is undeniably important for meeting Sustainable Development Goals (SDGs) and its targets in Nigeria's Niger Delta Region. Access to safe drinking water for the population's health and comfort remains a challenge in the core Niger Delta. Development partners and other funders from around the world work in developing nations to meet water needs through water access programs[1-14]. Too often the importance of environmental geochemistry has become more important in recent years as a means of distinguishing between man-made contamination and geogenic origins. Previous research has shown that exposure to certain trace elements in drinking water has a negative human health impact[15-20]. This is the case of exposure to several reports by different authors[21-28]. Thus, human reliance on groundwater resources has increased dramatically in the last 50-60 years as a result of climate change, rapid urbanization, agricultural development and intensification, food scarcity, population growth and industrialization[29-40], as well as changed consumption patterns pose a remarkable challenge and are contributing toward the rise in groundwater pollution, which has become a severe environmental/public health concern in Rivers State's Ebocha-Obrikom Area in recent years[41-50]. Pollution and a scarcity of surface water are two main causes contributing to the growing demand for groundwater resources. As a result, the achievement of the goals of sustainable development is jeopardized[1,4,5,10,12,38,42-45]. As a result of living in the Anthropocene, it is obligated to limit pollution, shut material loops and secure the possibility of global economic activity within the planetary boundaries[42,47,48,51-54]. Citizens, in turn, require access to infrastructure, information and motivational assistance to contribute positively to this shift[55-60]. Groundwater is a significant source, accounting for almost 90% of available freshwater sources. It is utilized for direct drinking in many places of the world and serves one-third of the world's population[4,5,11,61-64]. It meets roughly 67% of the world's agricultural irrigation needs (food production), 22% for domestic purposes (drinking water and sanitation) and around 33% of the water supply necessary for industries[14-20,61,62]. Currently, around 34% of the world's total annual water demand is fulfilled by groundwater[4-8,28,34,35,40-45,62-64]. However, the contamination of the subsurface water has drawn 200 million people across 28 nations into danger, making groundwater pollution a global issue[21-23,28,31,33,34,41,43-45]. The prolonged carcinogenic exposure as well as non-carcinogenic pollutants even in trace amounts can produce human health impacts (hypertension, carcinogenic risk, respiratory effects, skin lesions, cardiovascular, diabetes and neurological issues, etc.) either individually or synergistically[4-8,11,12,38,65,66]. The risk of groundwater pollution is highly noticeable in as well as around gas flaring industrial regions posing a hazard to human health as well as a healthy ecosystem. Thus, groundwater plays an essential role in society by influencing people's lifestyles, health and habits and is an essential part of socialization. This seems to be an essential supply for a variety of activities including domestic requirements, drinking, agriculture, industrial, as well as other uses. For the past few decades, groundwater has been used to meet human water needs[4-8,11,12,38,45]. It is a crucial asset for the country economic prosperity, particularly in Nigeria's oil-rich Niger Delta Area. Groundwater quality has become one of humanity's primary concerns since, it is directly related to human well-being and the use of this groundwater contaminated with trace metals may present public and environmental health risks in the oil-rich Niger Delta Region of Nigeria, depending on the contamination status. While a large part of the population in Ebocha-Obrikom Area of Rivers State has no access to tap water, drilled wells as well as rivers constitute the only main water sources for drinking and domestic use for that population[4-8,11,12,34,38,43,45]. As a result, it was critical to assess the physical and chemical pollution condition of groundwater in Nigeria's oil-rich Niger Delta Region. Strikingly, assessing groundwater quality in terms of its physical and chemical qualities is critical before ingestion. As a result, the goal of this work was to examine, in light of the key trends, the link between the physicochemical and heavy metals in the study area in order to determine whether the water is safe for drinking as well as domestic use. This research is significant since groundwater in Nigeria's oil-rich Niger

Delta area is mostly utilized for irrigation as well as residential purposes and the consequence of groundwater pollution on environmental and human health has not been explored deeply and comprehensively. As a result of the occurrence of high heavy metal concentrations in the study area's groundwater, the current study sheds light on the relationship between physicochemical and heavy metals in the study area.

MATERIALS AND METHODS

Study area (Niger Delta-Ebocha-Obrikom geology): In this study, 34 samples of phreatic water were collected from nine sampling sites at the point-of-use between September, 2019 to August, 2020, the Niger Delta Basin is one of Nigeria's seven sedimentary basins. It is regarded as the most remarkable due to its petroliferous character and as a result, intensive hydrocarbon exploration as well as production operations that take place both on land and in the sea. The Agbada, Akata and Benin formations are the three main subgroups of the Niger Delta Basin. The highest level is the Benin formation, including significant volumes of non-sea sand, mostly sandstone, as well as gravel deposits[1,6,67-71]. Hydrocarbons are present in trace levels in the formation[6,68-72]. The Agbada Formation is located under the Benin Formation and above the Akata Formation. Reservoir rocks and seals are included in the formation[6,69-72]. The Akata Formation, which lies near the bottom, is approximately 7000 m thick and is composed of clay as well as shale. The formation is rich in organic materials and is thought to be the primary source of hydrocarbons in the research region[1,4-8]. The Ebocha-Obrikom Region sits inside Nigeria's oil and gas hub, one of the largest settlements in the Niger Delta, situated in Rivers State between latitudes 5°20N-5°27N and 6°40E-6°46E. The Ogba/Egbema/Ndoni area of Rivers State is where the Towns of Obie, Obor, Ebocha, Obrikom and Agip New Base are all located. The River Nkissa runs through the study research region to the North, the River Orashi to the West, the River Sombrero to the East and Omoku town to the South. Changes in water bodies, built-up areas, mangrove vegetation depletion along river and stream shorelines, vegetation, as well as wetlands are all examples of significant changes in land use/land cover in the area. According to the Nigerian Meteorological Agency, the annual rainfall ranges from 2100 mm to 4600 mm and the average temperature is between 30.0 and 33.0°C[4,5]. Likewise, because of the existence of businesses that release harmful oxides into the sky, it is situated in a tropical wet environment with lengthy and intense rainy seasons, making the rainwater unsafe for drinking. the combined hydrological effects of Batholomew and Santa Barbara Rivers in the South, the River Sombriero in the East and the Rivers Orashi and Santa Barbara in the North, as well, as Southwest, considerably influence the overall drainage pattern.

Field sample collection: The current investigation employed a sample allusion to that used by Olalekan *et al.*[38], Raimi *et al.*[4] and Raimi *et al.*[5], sampling in a densely populated environment was concentrated in sensitive locations. These areas are still being polluted not only as a result of their location but also due to the ongoing exploration and production of crude oil. taken from the sample location's groundwater sources, which are primarily used for drinking and residential uses (Table 1). Both groundwater via dug wells or shallow pumping wells primarily designed for domestic usage was tested. The wells are 10 to 28 m deep, demonstrating that they are located in a phreatic aquifer. The sampling sites was recorded using portable GPS devices. For the objectives of this investigation, groundwater sources in the vicinity of the facility were picked at random but at various distances from each other. Also, after approximately 20 min of continuous water flow, for ground water (boreholes and wells), samples were physically taken at nine key points across the study region and placed in previously cleaned, plastic sampling bottles to ensure adequate aquifer quality that can be appropriately represented.

Groundwater samples remained collected from wells as well as boreholes at each of the nine locations once a month. All of the samples were collected during the day, from 9:00 am to 4:00 pm. As a result of instability, floods and the COVID-19 shutdown. Night samples were not taken and the sampling took place between September, 2019 to August, 2020. The depth varied between 10 and 28 m.

Table 1: Geographical coordinates of the nine sampling sites (samples)

S/N	Locations	Altitude (m)	Latitude	Longitude
Site 1	(Borehole) Opposite Ijeoma Quarters. 750 m away from Agip Gas Flaring Center Ebocha	10	Lat N05°27'068"	Long E006°41'480"
Site 2	(Borehole) 200 m Opposite Agip Gas Flaring Centre Ebocha and 50 m from Agip Waste Pit	-	Lat N05°27'28.7"	Long E006°41'58.1"
Site 3	(Well) The Apple Hotel 500 m from waste pit and 150 m away from Mgbede field oil well 7 Ebocha	16	Lat N05°27'37.5"	Long E006°42'05.3"
Site 4	(Well) 1000 m away from the Agip Flare Stack Ebocha	22	Lat N05°26'51.5"	Long E006°41'38.8"
Site 5	(Borehole) Abacha Road Obrikom, 800 m away from Agip gas plant	-	Lat N05°23'48.6"	Long E006°40'36.8"
Site 6	(Borehole) Eagle Base Obor, 2,500 m away from Agip gas plant	28	Lat N05°23'00.9"	Long E006°41'07.4"
Sites 7	(Well) Obor Road Obie, 2000 m away from Agip gas plant	24	Lat N05°23'22.5"	Long E006°40'49.1"
Sites 8	(Borehole) Green River Plant Propagation Centre Naoc 3000 m away from Agip gas plant	17	Lat N05°24'18.9"	Long E006°40'55.0"
Sites 9	35,000 m from Ebocha	-	Lat N5°4'58.1412"	Long E6°39' 30.4806"

Sampling, preservation and analysis: Water sampling, conservation, transportation and analysis followed the usual protocols indicated in Olalekan *et al.*[38], Raimi *et al.*[4], Raimi *et al.*[5] and American Public Health Association (APHA)[73]. Temperature, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Total Dissolved Substance (TDS), turbidity and Total Dissolved Solids (TDS) were all measured in the field using the HANNA water quality checker[73].

Ground water collection: Ground water samples were collected in pre-rinsed 1 L plastic containers for analysis of physicochemical characteristics. Prior to storage, "pre-rinsed water groundwater samples for heavy metal analyses were collected with nitric acid in 1 L containers and treated with 2 mL nitric acid (assaying 100%, Trace Metal Grade, Fisher Scientific)". This was done to maintain the oxidation conditions of the metals steady. Two sets of 250 mL glass-stoppered reagent bottles were used to collect groundwater samples at each sampling location for the Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO) tests. The bottles were sealed in black polythene bags after the BOD samples were carefully filled without trapping air. This was done to eliminate the presence of light in the samples, which can cause autotrophs to produce DO (algae). Before being added to two millilitres of each sample, the BOD samples were grown for five days. Winkler solutions I and II use a variety of dropping pipettes to slow down extra biological activity "in each sample, the bottles were carefully shaken to precipitate the floc that was at the bottom of the bottles. Winkler solution I is a manganese sulphate solution, whereas Winkler solution II is a combination of sodium or potassium iodide, sodium or potassium hydroxide, sodium azide (sodium nitride), with sodium hydroxide".

The DO samples were collected in transparent bottles with tight-fitting stoppers. Winkler I and II were used to preserve dissolved oxygen samples on the spot, which is comparable to that of the samples of BOD[73]. All samples had been meticulously identified as well as maintained at 4°C for easy identification. Electrical Conductivity (EC), Total Dissolved Solids (TDS), Alkalinity (Alka), pH, as well as temperature were measured on-site to estimate the amounts of unstable as well as sensitive water quality indicators (Temperature). As a result, Fig. 1. displayed the primary approaches for determining the composition of groundwater.

Quality Assurance and Quality Control (QA/QC): Importantly, all analytical procedures were meticulously monitored utilizing high-purity analytical reagents and solvents, as well as quality assurance and control techniques. Calibration standards were used to calibrate the equipment. The use of process blanks, triplicate analysis and the inspection of certified reference materials were all part of the analytical technique validation (CRM). Each organic contaminants limit of detection (LoD), repeatability, precision, reproducibility and accuracy in groundwater samples were measured.

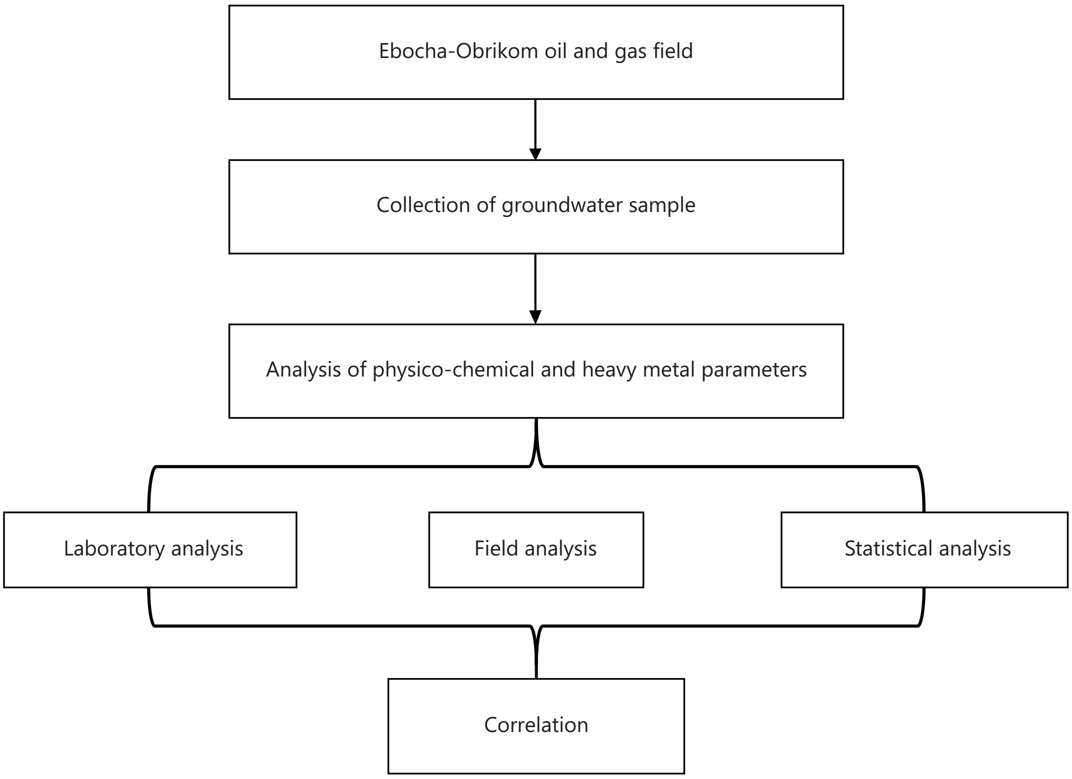

Fig. 1: A diagram depicting the quantification methods used in the current investigation

Statistical analysis: Inferential and descriptive data were analyzed using SPSS version 27 (IBM incorporation, USA). Mean was compared using a One-way Analysis of Variance (ANOVA) followed by the Duncan's Multiple Range Test (DMRT). The significance level was set at $p<0.05$.

RESULTS

Nature and strength of the bivariate relationship between any of the physio-chemical parameters during rainy and dry seasons as shown in Table 2 and 3. The result reveals that temperature has a significant positive relationship with pH. Also, the result recorded that conductivity has a significant positive relationship with pH. Similarly, the result shows that DO have a positive relationship with Temperature and pH. The results of the bivariate relationship also revealed that BOD has a significant positive relationship with temperature, pH and DO. The COD shows a significant negative relationship with temperature, pH, DO and BOD. Temperature, pH, DO, BOD. Acidity shows a significant positive relationship with Temperature, pH, DO, BOD and significant negative relationship with COD. Alkalinity shows a significant negative relationship with Temperature, pH, DO and BOD and Acidity but a significant positive relationship with COD. Temperature, pH, DO, BOD, Acidity, COD. For Hardness, it was positive and significantly related to pH, conductivity, DO, BOD and Acidity, but significantly negatively related with COD and Alkalinity. Additionally, the result revealed that TDS has a significant positive relationship with pH, Conductivity, BOD, Acidity, Hardness, but significantly negatively related with Turbidity and COD. The TSS also show a significant negative relationship with Temperature, pH, DO, Acidity, TDS, but significantly positive related with COD and Alkalinity. Also, salinity has a significantly positive relationship with Turbidity. The result of the bivariate relationship also reveals that chloride has a significant positive relationship with COD, Alkalinity, TSS but significant negative relationship with Temperature, DO, Acidity. Fluoride shows a significant negative relationship with pH, Chloride but significantly positive a relationship with Alkalinity. Results indicate that Aluminum has a significant negative relationship with conductivity, DO, Hardness, TDS but significant positive relationship with Turbidity, Alkalinity, TSS. Salinity and fluoride. Sodium showed a significant negative relationship with Temperature, DO, Acidity but a significant positive relationship with COD, Alkalinity, TSS, Chloride, Fluoride, Aluminum. Potassium showed a significant positive relationship with BOD, Hardness, TDS, TSS, Chloride, Sodium but significant negative relationship with Temperature. Similarly, the results show that calcium has a significant negative relationship with temperature, pH, DO, BOD, Acidity, Hardness, TDS, but significant positive relationship with Turbidity, COD, Alkalinity, TSS, Salinity, Chloride, Aluminum, Sodium. Iron was found to have significant positive relationship with Salinity, Fluoride, Aluminum and Turbidity. While magnesium showed a significant positive relationship with Temperature, DO, BOD, COD, Acidity, Hardness, TDS but significant negative relationship with Alkalinity, TSS, Chloride, Sodium and Calcium. The result indicates that Zinc has a significant positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium but significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium. Additionally, the results reveal that manganese has a significant positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Calcium, Magnesium, Zinc but a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium. Also, the result recorded that Cadmium has a significant positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, Magnesium, Iron, Zinc, Manganese but recorded a significant negative relationship with COD, Alkalinity, TSS, Chloride and Calcium. Similarly, the result shows that lead has a significant negative relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium, but a significant positive relationship with COD, Alkalinity, TSS, Chloride, Aluminum, Sodium, Calcium. While copper showed a significant direct positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium but had a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. Result indicates that Chromium has a significant positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Iron, Zinc, Manganese, Cadmium, Copper and significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. There was a significant positive relationship between sulphate and Temperature, pH, DO, BOD, Acidity, Magnesium, Iron, Zinc, Manganese, Cadmium, Copper, Chromium. While sulphate was a negatively significant relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. Ammonia revealed significant positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate and significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. Additionally, results indicate that phosphorus has a significantly positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia. While it shows a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. Similarly, the result shows that Nitrite has a positive relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate, but a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. The result of the bivariate relationship also reveals that Nitrate has a significant positive association with Temperature, pH, Turbidity, DO, BOD, Acidity, Hardness, Salinity, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate, Nitrite, but a significant negative relationship with COD, Alkalinity, TSS, Fluoride, Sodium, Calcium, Lead. Nickel showed a significant positive relationship with Temperature, pH, DO, BOD, Acidity, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate, Nitrite, Nitrate but a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium, Lead. Lastly, TPH shows a significant, positive relationship with Temperature, DO, Chloride, Sulphate, Ammonia, Nitrate, but shows a significant negative relationship with only Alkalinity and Fluoride.

Thus, the principal pollutants' impacts on human health were diagrammatically depicted in Fig. 2.

Table 2: Correlation between physicochemical and heavy metals for wet seasons

Correlations (rainy season)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Temp	1																
2. pH	0.350**	1															
3. Conduct.	-0.143	0.336**	1														
4. Turbidity	0.073	0.100	-0.188	1													
5. DO	0.553**	0.393**	0.063	0.190	1												
6. BOD	0.289*	0.340**	0.106	-0.098	0.399**	1											
7. COD	-0.449**	-0.258*	0.016	0.128	-0.569**	-0.462**	1										
8. Acidity	0.582**	0.392**	-0.012	0.026	0.683**	0.459**	-0.806**	1									
9. Alkalinity	-0.380**	-0.406**	-0.038	-0.130	-0.660**	-0.297*	0.488**	-0.740**	1								
10. Hardness	0.054	0.382**	0.386**	-0.015	0.421**	0.610**	-0.347**	0.353**	-0.450**	1							
11. TDS	0.023	0.267*	0.479**	-0.281*	0.212	0.405**	-0.310*	0.358**	-0.227	0.542**	1						
12. TSS	-0.361**	-0.368**	0.039	0.162	-0.443**	-0.220	0.651**	-0.725**	0.632**	-0.244	-0.314*	1					
13. Salinity	0.061	-0.058	-0.101	0.711**	0.106	0.034	-0.032	0.123	-0.065	0.095	-0.101	0.051	1				
14. Chloride	-0.281*	-0.093	0.149	0.092	-0.336**	-0.233	0.709**	-0.590**	0.258*	-0.077	-0.137	0.445**	-0.108	1			
15. Flouride	-0.010	-0.282*	-0.145	0.061	-0.218	0.137	-0.177	-0.044	0.302*	-0.221	-0.198	0.240	0.223	-0.249*	1		
16. Al	-0.042	-0.170	-0.367**	0.546**	-0.263*	-0.003	0.092	-0.139	0.273*	-0.256*	-0.398**	0.383**	0.484**	-0.080	0.679**	1	
17. Na	-0.427**	-0.233	0.089	0.050	-0.541**	-0.091	0.442**	-0.587**	0.668**	-0.116	-0.194	0.507**	0.159	0.356**	0.400**	0.464**	1
18. K	-0.250*	-0.207	0.194	0.189	-0.028	0.326**	0.105	-0.070	0.027	0.450**	0.393**	0.327**	0.246	0.283*	0.172	0.229	0.310*
19. Ca	-0.361**	-0.326**	-0.132	0.378**	-0.563**	-0.500**	0.766**	-0.748**	0.601**	-0.359**	-0.432**	0.667**	0.279*	0.579**	0.130	0.450**	0.620**
20. Mg	0.350**	0.218	0.162	-0.024	0.582**	0.490**	-0.667**	0.821**	-0.603**	0.463**	0.476**	-0.517**	0.168	-0.571**	-0.020	-0.141	-0.444**
21. Fe	0.149	0.113	-0.149	0.535**	0.166	0.084	-0.051	0.121	-0.020	-0.124	-0.095	0.093	0.487**	-0.234	0.463**	0.564**	0.124
22. Zn	0.497**	0.517**	0.156	0.095	0.688**	0.502**	-0.582**	0.822**	-0.768**	0.572**	0.440**	-0.620**	0.166	-0.250*	-0.180	-0.177	-0.398**
23. Mn	0.417**	0.252*	0.013	-0.139	0.529**	0.612**	-0.564**	0.687**	-0.538**	0.336**	0.438**	-0.550**	-0.016	-0.361**	0.003	-0.169	-0.434**
24. Cd	0.386**	0.391**	-0.045	-0.037	0.512**	0.469**	-0.518**	0.531**	-0.343**	0.310*	0.241	-0.477**	0.201	-0.559**	0.097	-0.035	-0.157
25. Pb	-0.417**	-0.329**	0.080	0.063	-0.656**	-0.448**	0.573**	-0.748**	0.676**	-0.293*	-0.369**	0.662**	0.059	0.415**	0.169	0.266*	0.610**
26. Cu	0.514**	0.368**	0.019	-0.129	0.564**	0.520**	-0.763**	0.848**	-0.633**	0.264*	0.460**	-0.689**	0.034	-0.518**	0.062	-0.170	-0.540**
27. Cr	0.360**	0.248*	-0.155	0.037	0.431**	0.593**	-0.516**	0.590**	-0.395**	0.376**	0.425**	-0.422**	0.230	-0.473**	0.114	0.054	-0.280*
28. Sulphate	0.567**	0.425**	-0.090	0.183	0.700**	0.286*	-0.456**	0.582**	-0.460**	0.144	0.027	-0.362**	0.152	-0.323**	0.029	-0.025	-0.539**
29. NH_3	0.555**	0.446**	0.111	0.002	0.724**	0.634**	-0.608**	0.768**	-0.617**	0.476**	0.450**	-0.533**	0.048	-0.249*	-0.039	-0.164	-0.434**
30. PO_4	0.441**	0.510**	0.163	-0.117	0.545**	0.587**	-0.618**	0.733**	-0.487**	0.421**	0.558**	-0.680**	0.038	-0.522**	-0.010	-0.179	-0.318*
31. Nitrite	0.590**	0.436**	0.150	0.132	0.801**	0.521**	-0.700**	0.850**	-0.701**	0.465**	0.402**	-0.537**	0.184	-0.348**	-0.036	-0.118	-0.501**
32. Nitrate	0.600**	0.484**	-0.011	0.261*	0.748**	0.394**	-0.426**	0.679**	-0.643**	0.367**	0.173	-0.437**	0.252*	-0.104	-0.301*	-0.217	-0.547**
33. Nickel	0.501**	0.285*	-0.004	0.068	0.569**	0.360**	-0.587**	0.670**	-0.536**	0.218	0.108	-0.473**	0.115	-0.485**	-0.004	-0.130	-0.503**
34. TPH	0.332**	0.193	0.141	0.170	0.306*	0.161	0.208	0.036	-0.273*	0.133	-0.010	0.103	0.080	0.400**	-0.271*	-0.209	-0.197

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
18. K	1																
19. Ca	0.208	1															
20. Mg	0.160	-0.672**	1														
21. Fe	0.118	0.172	0.153	1													
22. Zn	0.152	-0.549**	0.696**	0.119	1												
23. Mn	0.147	-0.604**	0.631**	0.161	0.669**	1											
24. Cd	-0.140	-0.441**	0.452**	0.262*	0.542**	0.549**	1										
25. Pb	0.055	0.680**	-0.658**	-0.151	-0.661**	-0.825**	-0.499**	1									
26. Cu	-0.067	-0.733**	0.701**	0.070	0.700**	0.722**	0.568**	-0.730**	1								
27. Cr	0.205	-0.418**	0.577**	0.267*	0.619**	0.629**	0.615**	-0.577**	0.618**	1							
28. Sulphate	-0.117	-0.417**	0.413**	0.361**	0.505**	0.464**	0.480**	-0.496**	0.535**	0.358**	1						
29. NH_3	0.159	-0.605**	0.650**	0.222	0.851**	0.775**	0.569**	-0.736**	0.744**	0.639**	0.687**	1					
30. PO_4	0.017	-0.644**	0.701**	0.155	0.686**	0.694**	0.701**	-0.662**	0.785**	0.705**	0.512**	0.720**	1				
31. Nitrite	0.159	-0.633**	0.735**	0.180	0.856**	0.687**	0.502**	-0.692**	0.753**	0.599**	0.656**	0.876**	0.665**	1			
32. Nitrate	0.012	-0.382**	0.496**	0.094	0.775**	0.484**	0.428**	-0.551**	0.573**	0.489**	0.695**	0.745**	0.469**	0.796**	1		
33. Nickel	-0.156	-0.545**	0.569**	0.073	0.603**	0.475**	0.541**	-0.493**	0.666**	0.536**	0.549**	0.585**	0.617**	0.580**	0.593**	1	
34. TPH	0.007	-0.057	0.031	-0.124	0.230	0.034	0.074	-0.053	0.107	-0.045	0.275*	0.298*	0.011	0.235	0.419**	0.162	1

**Correlation is significant at the 0.01 level (2-tailed) and *Correlation is significant at the 0.05 level (2-tailed)

Table 3: Correlation between physicochemical and heavy metals for dry seasons

	Correlations (dry season)																																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1. Temp	1																																	
2. pH	0.056	1																																
3. Conduct.	0.017	0.110	1																															
4. Turbidity	-0.038	0.051	0.158	1																														
5. DO	0.515**	0.165	0.251	0.315*	1																													
6. BOD	-0.163	0.290	0.141	-0.141	-0.245	1																												
7. COD	-0.254	0.186	0.167	0.083	-0.069	0.140	1																											
8. Acidity	0.323*	0.067	-0.070	0.168	0.332*	0.102	-0.055	1																										
9. Alkalinity	-0.002	-0.134	0.056	0.141	0.156	0.020	0.129	0.084	1																									
10. Hardness	-0.327*	0.381**	0.411**	-0.015	-0.307*	0.802**	0.290	-0.175	0.012	1																								
11. TDS	-0.453**	0.130	0.305*	0.178	-0.148	0.474**	0.257	0.139	0.153	0.636**	1																							
12. TSS	-0.084	0.382**	0.410**	0.071	-0.009	0.796**	0.178	0.091	0.234	0.818**	0.556**	1																						
13. Salinity	-0.024	0.014	0.222	0.282	0.363*	-0.194	-0.134	0.162	0.045	-0.042	0.336*	0.066	1																					
14. Chloride	-0.059	0.282	0.410**	0.001	-0.036	0.280	0.339*	-0.111	-0.203	0.554**	0.520**	0.232	0.157	1																				
15. Flouride	-0.219	-0.163	-0.103	0.157	-0.379*	0.389**	-0.054	0.128	0.040	0.367*	0.426**	0.338*	-0.085	-0.104	1																			
16. Al	-0.320*	-0.162	0.079	0.492**	-0.159	0.182	0.085	0.227	0.267	0.161	0.293	0.245	-0.027	-0.309*	0.612**	1																		
17. Na	-0.377*	-0.019	0.048	-0.054	-0.363*	0.650**	0.356*	-0.211	0.231	0.654**	0.550**	0.488**	0.038	0.412**	0.321*	0.189	1																	
18. K	-0.500**	0.206	0.371*	0.140	-0.188	0.567**	0.348*	-0.005	0.033	0.771**	0.952**	0.618**	0.295*	0.583**	0.391**	0.246	0.642**	1																
19. Ca	0.046	-0.092	0.469**	0.274	0.040	0.084	0.276	0.034	0.479**	0.315*	0.424**	0.296*	0.261	0.332*	0.308*	0.286	0.353*	0.361*	1															
20. Mg	-0.683**	0.079	0.145	0.071	-0.408**	0.145	0.192	-0.096	-0.375*	0.352*	0.604**	0.045	0.226	0.309*	0.283	0.264	0.212	0.642**	-0.005	1														
21. Fe	0.133	0.062	0.064	0.248	0.342*	0.026	-0.221	0.382**	0.022	-0.130	0.232	0.123	0.160	-0.164	0.317*	0.438**	-0.084	0.106	0.114	0.024	1													
22. Zn	0.226	0.285	0.440**	0.333*	0.248	0.203	0.224	0.076	-0.201	0.367*	0.285	0.301*	0.180	0.532**	0.102	0.085	0.160	0.344*	0.338*	0.070	0.250	1												
23. Mn	-0.225	0.278	0.434**	0.163	0.092	0.485**	0.326*	0.246	-0.151	0.550**	0.777**	0.508**	0.295*	0.505**	0.226	0.172	0.387**	0.824**	0.223	0.596**	0.238	0.389**	1											
24. Cd	0.139	0.033	0.098	0.255	0.386**	0.215	0.252	0.261	0.629**	0.053	-0.036	0.359*	0.088	-0.391**	0.090	0.423**	0.214	-0.018	0.323*	-0.360*	0.154	0.003	0.026	1										
25. Pb	0.005	-0.124	0.151	-0.021	-0.075	-0.109	-0.016	0.047	-0.180	-0.058	0.060	0.083	0.478**	0.091	-0.111	-0.121	0.115	0.040	0.054	0.052	-0.005	0.063	0.080	-0.132	1									
26. Cu	0.005	0.206	0.058	-0.006	0.043	0.441**	0.153	0.038	0.276	0.321*	0.187	0.263	-0.208	0.140	-0.030	0.106	0.460**	0.269	0.047	0.006	0.080	0.085	0.278	0.393**	-0.367*	1								
27. Cr	-0.132	0.353*	0.340*	0.078	-0.079	0.805**	0.217	0.141	0.304*	0.820**	0.497**	0.882**	-0.091	0.165	0.455**	0.372*	0.505**	0.581**	0.348*	0.095	0.079	0.240	0.480**	0.451**	-0.210	0.429**	1							
28. Sulphate	0.665**	0.077	-0.014	0.165	0.678**	-0.319*	-0.095	0.295*	0.017	-0.449**	-0.267	-0.121	0.096	-0.175	-0.304*	-0.193	-0.478**	-0.341*	0.016	-0.516**	0.343*	0.157	-0.063	0.244	-0.030	-0.062	-0.254	1						
29. NH_3	0.261	0.247	0.256	0.139	0.364*	0.480**	-0.034	0.309*	-0.018	0.423**	0.486**	0.566**	0.217	0.401**	0.120	-0.065	0.263	0.475**	0.282	-0.117	0.344*	0.484**	0.486**	0.160	0.022	0.254	0.405**	0.442**	1					
30. PO_4	-0.006	0.136	0.040	0.085	0.087	0.494**	-0.017	0.403**	0.470**	0.272	0.116	0.593**	-0.129	-0.432**	0.387**	0.490**	0.144	0.098	0.125	-0.191	0.324*	-0.099	0.112	0.698**	-0.166	0.350*	0.682**	-0.007	0.196	1				
31. Nitrite	-0.043	0.243	0.419**	0.362*	0.388**	-0.076	0.301*	0.138	-0.301*	0.165	0.427**	0.086	0.526**	0.490**	-0.065	0.023	-0.005	0.461**	0.207	0.395**	0.197	0.574**	0.529**	-0.036	0.231	-0.055	-0.047	0.239	0.419**	-0.318*	1			
32. Nitrate	0.450**	0.150	0.582**	0.332*	0.655**	-0.169	-0.004	0.182	-0.041	0.025	0.103	0.156	0.514**	0.292	-0.171	-0.143	-0.258	0.098	0.468**	-0.140	0.204	0.520**	0.256	0.182	0.166	-0.112	0.028	0.577**	0.545**	-0.074	0.658**	1		
33. Nickel	0.242	0.130	0.043	0.051	0.213	-0.075	-0.051	0.163	-0.354*	-0.089	-0.131	0.063	0.210	0.036	-0.145	-0.107	-0.252	-0.110	-0.144	-0.057	0.133	0.169	-0.014	-0.002	0.356*	-0.218	-0.129	0.372*	0.224	-0.021	0.302*	0.341*	1	
34. TPH	0.230	-0.061	0.140	0.394**	0.588**	-0.246	0.249	0.217	0.261	-0.195	0.134	-0.070	0.466**	0.165	-0.124	0.028	0.103	0.086	0.461**	-0.228	0.210	0.286	0.111	0.437**	0.183	0.068	-0.150	0.511**	0.411**	-0.111	0.606**	0.614**	0.205	1

**Correlation is significant at the 0.01 level (2-tailed) and *Correlation is significant at the 0.05 level (2-tailed)

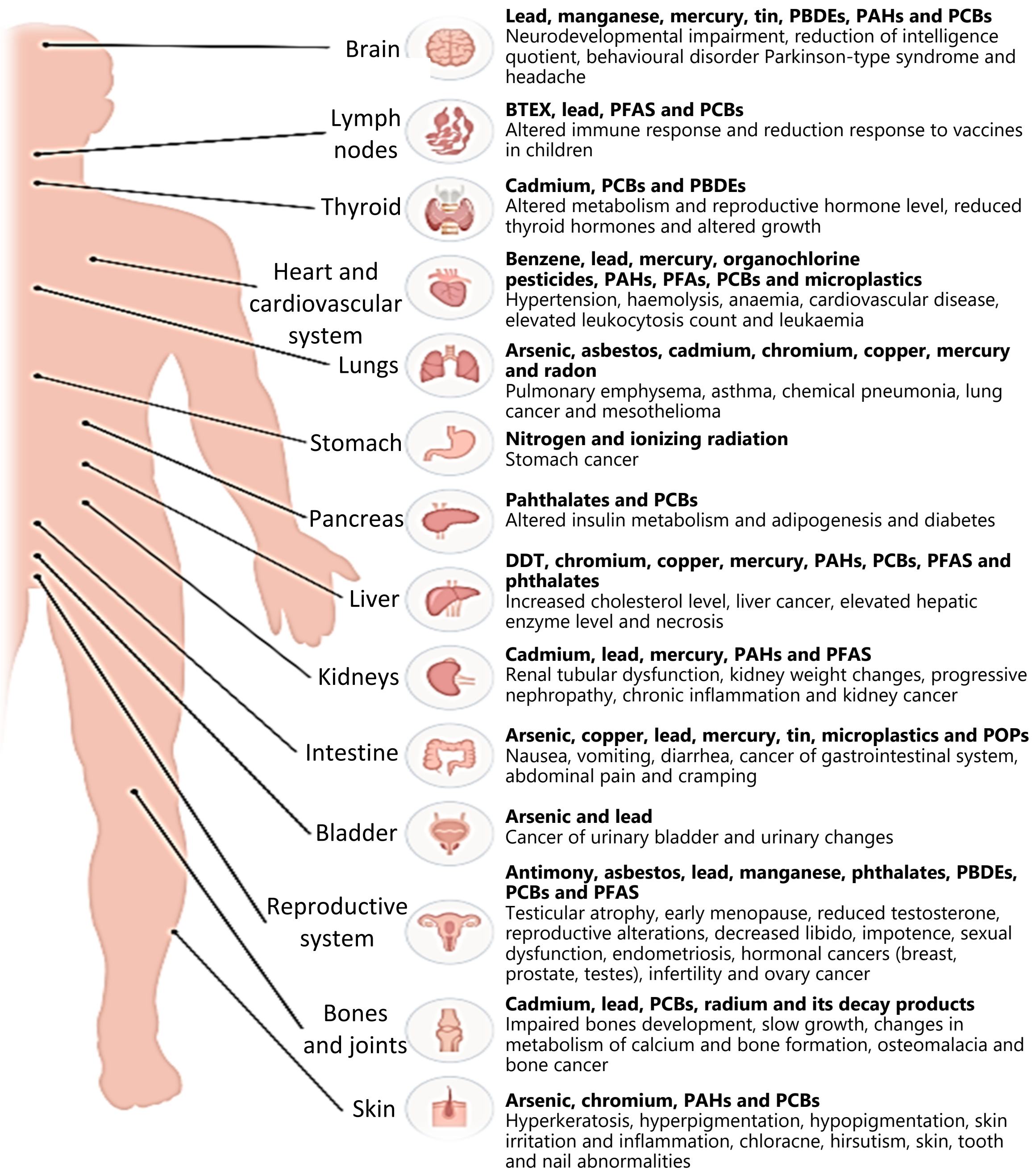

Fig. 2: Main effects of contaminants on human health, indicating the organs or systems affected and the contaminants causing them
Adapted from Raimi *et al.*[4] and Raimi *et al.*[105]

DISCUSSION

The correlation matrix (CM) is known in water chemistry as a popular and helpful statistical technique to know the positive and negative association of ions. A positive strong connection might imply the same sources of certain ions, which can be natural or anthropogenic in origin, whereas, a weak correlation shows that the sources of ions are independent of each other[73-76]. Thus, the correlation between and across different location sources contributes to the groundwater quality of the Ebocha-Obrikom Area of Rivers State. The groundwater in the studied region is largely used for drinking as well as domestic uses by the residents. As a result, due consideration should be paid to determining its fitness for human consumption. Table 2 and 3 showed the concentrations of physicochemical characteristics in groundwater samples from the research region. The correlation matrix was utilized to assess the interdependence of thirty-four groundwater characteristics. The correlation coefficient table demonstrates that the majority of the investigated factors strongly correlate with each other at the 1% ($p<0.01$) and 5% ($p<0.05$) levels. Positive correlations at $p<0.01$ and $p<0.05$ identified between the majority of the examined heavy metals (HMs) imply that these metals were deposited in the same atmosphere or came from comparable lithogenic sources[40]. There is a positive correlation between conductivity with pH, indicating that a rise in temperature, as well as conductivity, corresponds to an increase in groundwater pH concentrations. Also, it shows that pH contributes significantly to conductivity and suggests that considerable anthropogenic activities remain accountable for the addition of these groundwater ions into the area[76,77]. Likewise, BOD has a remarkable positive connection with temperature, pH and DO. Thereby showing that DO and BOD concentration went in parallel with the concentration of Temperature, pH and DO, thus sharing a similar origin in the water. The COD shows a significant negative relationship with temperature, pH, DO and BOD. Negative correlations between these physicochemical parameters could mean that these parameters have their origin from different sources[78]. Acidity shows a significant negative relationship with COD indicating the medium effect of acidity on the dissolved content of the water. Alkalinity shows a significant negative relationship with temperature, pH, DO and BOD. For hardness, it was significantly negatively related to COD and Alkalinity. Furthermore, the result revealed that TDS has a substantial positive association with pH, Conductivity, BOD, Acidity and Hardness thus, indicating that salt dissolution accelerates the electrical process of weathering. In the case of the study area, the inputs of Mg, SO_4, Na, Cl, TDS, as well as NO_3 remain influenced via precipitation as well as human-induced activities but are significantly negatively related to Turbidity and COD. On the other hand, the study found an interesting pattern between chloride showing a significant positive relationship with COD, Alkalinity and TSS but a significant negative relationship with Temperature, DO and Acidity, suggesting that weathering of halite and silicates is an important process, though may not the sole process, regulating water chemistry in the area. Results indicate that Aluminum has a significant negative relationship with conductivity, DO, Hardness and TDS but a significant positive relationship with Turbidity, Alkalinity, TSS, Salinity and fluoride. Sodium showed a significant negative relationship with Temperature, DO and Acidity but a significant positive relationship with COD, Alkalinity, TSS, Chloride, Fluoride and Aluminum. All of this may be attributable to Halite (NaCl) as well as Sylvite (KCl) mineral dissolution, as well as irrigation return flow[79]. It also revealed the cation exchange process in the groundwater system, which might be related to weathering as well as dissolution of sedimentary rocks containing F-bearing minerals in the vicinity (e.g., biotite, cryolite and amphiboles). Thus, indicating that ion-exchange reactions also occurred during the interaction between water and aquifer. Potassium showed a significant positive relationship with BOD, Hardness, TDS, TSS, Chloride and Sodium. Although all the aforementioned correlations between parameters are positive, but a significant negative relationship with Temperature. Similarly, the results show that calcium has a significant negative relationship with temperature, pH, DO, BOD, Acidity, Hardness and TDS but a significant positive relationship with Turbidity, COD, Alkalinity, TSS, Salinity, Chloride and Aluminum, Sodium revealing the fertilizers impact in the groundwater and likely metals co-enrichment through the mentioned ions as well as evaporitic formations as possible sources as recommended by Srivastava and Ramanathan[80]. Iron was found to have a significant positive relationship with Salinity, Fluoride, Aluminum and Turbidity, which remained ascribed to comparable geochemical procedures as well as circumstances for groundwater release of these metals[80-82]. The highly negative value was observed between Magnesium and Alkalinity, TSS, Chloride, Sodium and Calcium and Magnesium with COD, Alkalinity, TSS, Chloride, Sodium and Calcium. As well as Manganese with COD, Alkalinity, TSS, Chloride and Sodium. Thus, the weak correlations obtained between the parameters confirm that oxidation-reduction and leaching seem to be the probable sources of minerals and metals in groundwater of the generalized aquifers of the Ebocha-Obrikom Area of Rivers State. The different geological formations of these aquifers clearly show that groundwater mineralization is intimately linked to the nature of the geology and geomorphology of the area which is dominant in the study area. Also, cadmium shows a strong negative correlation between COD, Alkalinity, TSS, Chloride and Calcium. Lead has a significant negative relationship with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese and Cadmium, while copper had a significant negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium and Lead. The result indicates that Chromium has a strong negative relationship with COD, Alkalinity, TSS, Chloride, Sodium, Calcium and Lead remain remarkably correlated since they contribute toward water hardness. There is a positive correlation between Sulphate and Temperature, pH, DO, BOD, Acidity, Magnesium, Iron, Zinc, Manganese, Cadmium, Copper and Chromium. Ammonia with Temperature, pH, DO, BOD, Acidity, Hardness, TDS, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium and Sulphate positive correlations show that species studied come from comparable sources but also show the existence of chemical reactions in groundwater, like cations and anions neutralization. All of these indicate the process of neutralization between all measured parameters that occurred during the studied period. The result of the bivariate relationship also revealed that Nitrate has a significant positive association with Temperature, pH, Turbidity, DO, BOD, Acidity, Hardness, Salinity, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate, Nitrite elucidate the presence of anthropogenic sources such as punctured sewer pipelines[82,83] and gas flaring but significant negative relationship with COD, Alkalinity, TSS, Fluoride, Sodium, Calcium and Lead. There is positive correlation between Nickel with Temperature, pH, DO, BOD, Acidity, Magnesium, Zinc, Manganese, Cadmium, Copper, Chromium, Sulphate, Ammonia, Phosphate and Nitrite. Also, TPH shows a significant, positive relationship with Temperature, DO, Chloride, Sulphate, Ammonia and Nitrate, all suggesting that high correlation between metals could be the reason of same origin and controlling factors. The highly negative value was observed between Nitrate and COD, Alkalinity, TSS, Chloride, Sodium, Calcium, as well as Lead. Lastly, TPH shows a significant negative relationship with only Alkalinity and Fluoride. This finding is consistent with previous studies, as observed in the present study[40,76-83].

Turning to the association for dry seasons (Table 3), there is positive correlation between DO with Temperature and Turbidity. Acidity with Temperature and DO. Hardness with pH, conductivity and BOD. TDS with Conductivity, BOD and Hardness, this strong correlation explains ions exchange between TDS and conductivity. The TSS with pH, Conductivity, BOD, Hardness and TDS. Salinity with DO and TDS. Chloride with Conductivity, COD, Hardness and TDS, suggesting that weathering is an important process, though may not be the sole process, regulating water chemistry in the area. Fluoride with BOD, Hardness, TDS and TSS, indicating the likelihood contribution of carbonate dissolution to water chemistry[84]. This was evidenced by the fact that the study area is carbonates in nature such as calcite and dolomite are common in the geological formations. Aluminum with Turbidity, Fluoride suggested that these metals were released into groundwater by forming complexes in solution with evaporites[80,85]. Sodium with BOD, COD, Hardness, TDS, TSS, Chloride and Fluoride may be attributed to the dissolution of Halite (NaCl) and Sylvite (KCl) minerals and irrigation return flow[79]. It also possibly suggests a common geogenic origin and conditions that enhanced its mobility. Thus, this showed that the halite dissolution and the silicate weathering provided solute components, such as feldspar. Potassium with conductivity, BOD, COD, Hardness, TDS, TSS, Salinity, Chloride, Fluoride and Sodium. Calcium with Conductivity, Alkalinity, Hardness, TDS, TSS, Chloride, Fluoride, Sodium and Potassium indicating the possible co-enrichment of these metals with the mentioned ions and evaporitic formations as potential sources as suggested by Barzegar *et al*.[81]. It also suggested that some of these ions may have been derived from calcite dissolution. Magnesium with Hardness, TDS, Chloride and Potassium indicate that hardness is mostly related to Mg^{2+}. Not only anthropogenic sources but natural sources are also affecting groundwater quality. Iron with DO, Acidity, Fluoride and Aluminum. Zinc with Conductivity, Turbidity, Hardness, TSS, Chloride, Potassium and Calcium. The positive correlation between these parameters is in agreement with earlier similar results reported by Kumar *et al*.[86]. Strong positive correlation between Potassium and Calcium was also reported by Egbueri and Mgbenu[87]. Manganese has a significant positive relationship with conductivity, BOD, COD, Hardness, TDS, TSS, Salinity, Chloride, Sodium, Potassium, Magnesium and Zinc. A positive correlation between these parameters is an indication of their common sensitivity to redox reactions leading to the reduction of Sodium and Zinc Hydroxides and Manganese Oxides[87,88]. This also suggested a similar geogenic origin[86,88] and this study agreed with earlier similar results by Ukah *et al*.[89]. The highly positive correlation was observed suggests that high correlation between metals could be the reason for the same origin and controlling factors. Cadmium with DO, Alkalinity, TSS, Aluminum and Calcium, may be due to the fact that the production and refining processes of Al also contribute to the formation of Ca and Cd[89,90]. Lead with Salinity. Copper with BOD, Hardness, Sodium and Cadmium. Chromium with pH, Conductivity, BOD, Alkalinity, Hardness, TDS, TSS Fluoride, Aluminum, Sodium, Potassium, Calcium, Manganese, Cadmium and Copper which may be due to oxidation mechanism present in groundwater. All these parameters may have triggered groundwater mobilization. Sulphate with Temperature, DO, Acidity and Iron. Ammonia with DO, BOD, Acidity, Hardness, TDS, TSS, Chloride, Potassium, Iron, Zinc, Manganese, Chromium and Sulphate. Thus, positive correlations probably suggest that the parameters analyzed come from similar sources, but also indicate the presence of chemical processes in the groundwater, such as the neutralization between anions and cations. For example, the correlation between Ammonia, Chlorides and Sulphates, indicates the process of neutralization between parameters that occurred during the studied period. Phosphate with BOD, Acidity, Alkalinity, TSS, Fluoride, Aluminum, Iron, Cadmium, Copper, Chromium. Nitrite with Conductivity, Turbidity, DO, COD, TDS, Salinity, Chloride, Potassium, Magnesium, Zinc, Manganese and Ammonia. Nitrate with Temperature, Conductivity, Turbidity, DO, Salinity, Calcium, Zinc, Sulphate, Ammonia and Nitrite. This is in agreement with the observation of Khan and Jhariya[91], confirming the observation made by the Hierarchical cluster analysis. Nickel with Lead, Sulphate, Nitrite and Nitrate.

The highly negative value was observed between hardness with temperature and DO. The TDS with Temperature. Fluoride with DO. Aluminum with Temperature. Sodium with Temperature and DO, Potassium with Temperature. Magnesium with Temperature, DO and Alkalinity. Cadmium with Chloride and Magnesium. Copper with Lead. Sulphate with BOD, Hardness, Fluoride, Sodium, Potassium and Magnesium. Phosphate with Chloride. Nitrite and Nickel with Alkalinity. TPH has a significant positive relationship with Turbidity, DO, Salinity, Calcium, Cadmium, Sulphate, Ammonia and Nitrite. Thus, human activity has become one of the most important factors influencing groundwater chemistry and even the dominant mechanism regulating the hydrochemical composition of groundwater across the global south[3-13,23-47,60,61]. For Nitrogen, it is an important indicator of contamination from human community, which has been widely used to indicate the anthropogenic inputs of pollutant from agricultural practice, domestic effluents and so on[4-8]. Generally, groundwater water in the Ebocha-Obrikom Area of Rivers State originates from anthropogenic sources of domestic life, gas flaring, agriculture fertilizer, oil spillage and livestock manure, etc. Thus, groundwater in these locations was influenced by anthropogenic contaminant inputs. Hence, the current results align with some but not all findings reported in previous studies assessing human health risks of trace elements in groundwater in the Niger Delta Region of Nigeria[91-94]. Specifically, several studies reported associations between the assessment of groundwater quality for drinking and irrigation purposes[4-8,95-111]. The current study observed an association between some physicochemical indices and heavy metals. Discrepancies may be due to assessment in differences, physicochemical and heavy metals measurement and study area. The general finding of higher levels of risky association between some physicochemical indices and heavy metals overall being associated with one another is in line with past literature examining the relationships between these variables[4,5,40,45,47,105]. Current findings regarding the association between physicochemical indices and heavy metals are in line with reporting in several studies[4,5,40,45,47,95,105,110]. All these multi-regional studies offer wide-ranging interactive information between significant indicators such as the association between groundwater pollution and environmental background. Thus, the current findings expand the literature by demonstrating this association within a longitudinal study and specifically in relation to changes in health risk patterns (Fig. 2). Additionally, this is the first study, to document an association between 34 parameters before and during the COVID-19 pandemic. Future studies are encouraged to provide highly valuable contributions to the literature. Meanwhile, the overall pollution impact on water bodies and ecosystems is far more difficult to predict. In conclusion, continuous exposure to trace metals causes respiratory irritation, renal failure, neurological impairments, immunosuppression, anemia, gastrointestinal as well as liver cancer, skeletal system abnormalities, liver inflammation and cardiovascular disorders. As a result, the principal pollutants' impacts on human health were diagrammatically depicted in Fig. 2. This finding additionally contributes to a pattern of future groundwater studies based on the impact of health outcomes. In light of these findings, it is concluded that it is essential that effective policies be implemented. Furthermore, increased efforts should be made to safeguard groundwater from anthropogenic contaminations in order to achieve sustainable groundwater development. The findings of this study not only add to the geochemical characterization of shallow groundwater in Nigeria's oil-rich Niger Delta Region but also provide vital information for authorities developing groundwater sustainable management plans in such areas.

Local-level data are crucial for monitoring pollution levels, identifying as well as assigning suitable responsibility for each pollution source, appraising intervention successes, directing enforcement, educating civil society and the public, as well as measuring improvement toward sustainable development goals. Set up systems to track pollution and its consequences on health. Incorporating modern technologies into pollution monitoring, like data mining as well as satellite imaging, can boost efficiency, broaden geographic coverage, as well as reduce costs. The availability of this data is critical and collaboration with civil society as well as the broader public will assure accountability while also raising public education awareness. Even tiny monitoring programs with only one or a few sampling sites can help governments and civil society organizations document pollution and analyze progress toward short and long-term management goals. To enable the sharing of successes and lessons gained, pollution management metrics control should be linked into SDG dashboards as well as other monitoring systems. Furthermore, the study recommendations will be useful for other oil-rich countries experiencing comparable challenges. Because every decision is based on a projection of its repercussions.

CONCLUSION

High-quality groundwater is critical in minimizing the prevalence of waterborne illnesses in rural regions. The current study's findings indicate a positive association between each of the criteria. That is, if the percentage change in any of the indices' parameters increases, there will be an increase in other parameters in Ebocha-Obrikom. In reality, a minor rise in these parameters could result in a significant increase in long-term oil and gas exploitation as well as gas flaring in the area, both of which have a dominant and universal effect on solute concentrations and hydrochemical types. It is important to note that gas flaring may not be the only factor influencing these metrics. In fact, there are numerous other elements that may be more relevant than gas flaring, such as oil spillage, bunkering, human activities, as well as distance from gas flaring sites, among others. Consequently, gas flaring data may have been underestimated, leading to a moderate correlation between each of the metrics. As a result, the consequences of heavy metal pollution on public health remain poorly understood, as well as its input to the global sickness burden is almost definitely understated. Surprisingly, the Pearson correlation analysis method results suggest that the composition of rock dissolution, as well as human activities, have an effect on the composition of groundwater in the research area. The key governing factors in Rivers State's Ebocha-Obrikom Area include evaporating dissolution, human activities and significant cation exchange, all of which affect the evolution of groundwater quality. Thus, the current study's findings provide critical insights into the changing dynamics and can be extrapolated to future exposures to environmental contaminants throughout developmentally vulnerable windows in early life, which could cause outbreaks of infectious respiratory disease as well as infancy death, childhood and chronic, no communicable diseases that can manifest at any point across the indigenous resident life span, as well as to inform policymakers of how these toxic chemical parameters are growing into a major threat to human's health in oil-rich Niger Delta Regions of Nigeria and also provided a reference to support prioritization and planning for heavy metals pollution control. While, disease as well as disability induced by heavy metal pollution have high economic expenses, which might jeopardize national development plans.

SIGNIFICANCE STATEMENT

The wise use and quality of groundwater for industrial, agricultural and drinking reasons have attracted a lot of attention as a result of environmental contamination and anthropogenic activities. Thus, to shed light on the causes, correlations of trace metal contamination in drinking water in oil exploration zones in groundwater pollution in the Niger Delta become necessary. Hence, the findings can serve as a foundation for making decisions on the scientific management of the Niger Delta groundwater ecosystem and the preservation of public health.

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