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Preliminary Study of Groundwater Quality Using Hierarchical Classification Approaches for Contaminated Sites in Indigenous Communities Associated with Crude Oil Exploration Facilities in Rivers State, Nigeria

Morufu Olalekan Raimi[1,2*], **Henry Olawale Sawyerr**[2]

[1]Department of Community Medicine, Environmental Health Unit, Faculty of Clinical Sciences, Niger Delta University, Amassoma, Bayelsa State, Nigeria
[2]Department of Environmental Health, Faculty of Pure and Applied Science, Kwara State University, Malete, Kwara State, Nigeria
Email: *morufuolalekan.raimi@gmail.com, *ola07038053786@gmail.com, hsawyerr@gmail.com

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Abstract

Background: Groundwater is an important source of water. Since the control and removal of pollution are expensive, it is essential to identify the possible sources of contamination and to correctly classify groundwater on the basis of its intrinsic and integrated vulnerability. **Objectives:** To group ground water chemical ions and heavy metals parameters into similar groups. **Method:** The investigation made use of standard analytical procedures. All sampling, conservation, transportation and analysis followed standard procedures described in APHA (2012). To prevent degradation of the organic substances, all obtained samples were transferred to the laboratory, while kept in an ice-box. **Results:** Sampling records from the same area are generally assigned to the same cluster during hierarchical cluster analysis (HCA). The cluster diagram shows the grouping of the heavy metal in the study area during wet and dry seasons. It reveals that 5 distinct clusters were identified for wet season and 4 clusters were identified during dry season. Also, it reveals that 5 distinct clusters were identified for wet season and for dry season, 4 distinct clusters were identified. **Conclusion:** The findings of this study are significant for policymakers and agencies in terms of dealing with the issues identified to enhance sustainable livelihood practices in the oil rich Niger Delta region of Nigeria. Therefore, decision-makers should take proper initiatives to get local people aware of the endangered zones before use, as drinking water is key to good health. Similarly, multinational oil companies will find it useful in their quest for viable social corporate responsibility and remediation plans in their respective host communities. The method proved to be a useful and objective tool for environmental planning.

Keywords

Potentially Toxic Elements, Environmental Pollution Assessment, Health Risk, Enrichment Factor, Planning, Crude Oil Exploration, Utilization, Core Niger Delta

1. Introduction

Approximately half of the world's population is affected by one or more of the six major diseases linked to water supply and sanitation at any one time 1) Diarrhea caused by a number of microbial and viral pathogens in food and water; 2) Ascaris; 3) Dracunculiasis; 4) Hookworm; 5) Schistosomiasis, all by infestation with various worms leading to disability, morbidity and sometimes death; 6) Trachoma caused by a bacterium, leading to blindness) [1]-[16]. In the underdeveloped world, almost 400 children under the age of five die every hour from watery diarrheal illnesses [16]. Longevity, decreased infant mortality, improved health, productivity, and material well-being are all considered benefits of development [1] [2]. In general, the inhabitants of developing nations do poorly on these indicators when compared to those of industrialized countries. The availability of abundant and safe water for residential use, as well as proper sanitation to dispose of waste, has long been recognized as critical to development, with advantages such as increased labor productivity extending across all sectors [3] [4] [5] [6] [7] [9] [10] [11] [12] [14]. Increased rivalry among water users for dwindling supplies of unpolluted water may be linked to water quality issues [17]-[25]. Pollutants can be human-made (such as salinization, microbiological contamination, eutrophication, excess nutrients, acidification, metal pollutants, toxic wastes, saltwater contamination, thermal pollution, and increases in total suspended solids) or natural pollutants (like fluoride as well as arsenic) [3] [4] [5] [8] [11] [12] [15] [16]. In highly populated areas where water is scarce and wastewater treatment is inadequate, poor water quality is progressively limiting agricultural and commercial growth [1] [2]. Water pollution has a negative impact on agricultural productivity and poses a health risk to fish, other aquatic life, especially humans [4] [5] [17] [18].

As a consequence of the ineffective and inefficient public water provision in the Ebocha-Obrikom region of Rivers State, which is caused by non-operational public water stations across the LGA, rural inhabitants resort to other sources of water like private boreholes for drinking and other domestic purposes [17]-[25]. This phenomenon has led to the proliferation of all kinds of water vending enterprises most of which do not meet the purification standard, thereby predisposing residents to water-related diseases that threaten the health of the residents [3] [4] [5] [11] [12] [13] [16]. As groundwater (GW) quality remain crucial for indigenous population of Nigeria's oil rich communities, their health, food system, societal stability and welfare [17]-[25]. While groundwater is extremely important as a life-sustaining factor, in view of this, an effort has been made for grouping heavy metals parameters into similar groups in Ebocha-Obrikom Area of Rivers State, Nigeria. While, the possibility of the presence of high heavy metal concentration in groundwater resources in a given area is known as groundwater potential from the standpoint of groundwater investigation [17]-[23] [26]. The geology, geomorphology, and physical layout of a region indicate the availability of groundwater. Over the years, high levels of groundwater contamination is observed in most parts of the country due to the percolation of toxic elements from industrial effluents [13] [15] [27] [28] [29] [30], landfills, and diffused polluters from pesticides and fertilizers [31]-[38]. Deterioration in groundwater quality can be due to natural processes such as the geological formation of rocks and numerous anthropogenic activities such as improper disposal and release of effluent from industries into surface water bodies which migrates under the action of leaching from unsaturated zone to groundwater effortlessly [39] [40]. Especially in the vastly industrialized and densely populated regions with shallow aquifers, groundwater contamination by anthropogenic wastes is a serious issue [41] [42]. Numerous studies have been conducted in various parts of Nigeria in determining the groundwater contamination and their sources of pollution [3] [4] [5] [11] [12] [15] [17]-[25] [43]-[51].

Few heavy metals such as Copper (Cu), Zinc (Zn), and Iron (Fe) are essential for human body metabolism, while the excess concentration of other heavy metals like Chromium (Cr), Cobalt (Co), Arsenic (As), and Cadmium (Cd) is highly toxic even at low concentration. Higher concentrations of such heavy metals in potable water can cause various health issues such as kidney, liver damages, and gastric cancer [17]-[25]. A higher amount of Cr via food or contaminated water can cause kidney damage, intestinal bleeding, and gastrointestinal stromal tumors [17]-[25]. The characterization of the heavy metal content in groundwater is necessary to fathom the source, fate, transport, and potential health risk [17] [18] [23] [43] [44]. With the unparalleled spatio-temporal availability and easy accessibility, groundwater plays an irreplaceable role in many aspects such as ecosystems, food security, energy and human health, especially in the core Niger Delta Region of Nigeria [52]-[59]. Besides water quantity, the hydrochemical composition is also a critical factor in determining the availability of the groundwater resource [17] [18] [20] [21]. However, groundwater quality usually encounters deterioration due to anthropogenic and natural factors [17]-[25]. Thus, knowledge of hydrogeochemical signatures and grouping of ground water chemical ions and heavy metals parameters into similar groups is primary to rational development of the groundwater resource and security of water supply [1] [2] [11] [12] [16]. This study is important as the groundwater in Ebocha-Obrikom area of Rivers State is majorly used for residential and irrigation purposes, and the impact of groundwater contamination on human health needs to be investigated. Thus, the present study insights into the grouping of ground water chemical ions and heavy metals parameters into similar groups due to the possibility of the presence of high heavy metal concentration in the groundwater of the study area [4] [5] [17]-[25]. This result is of great significance for insightful guidelines on domestic and management for agricultural activists, policymakers, as well as water managers. Also, it would provide pollution prevention and control of gas flaring and oil spillage in the core Niger Delta region of Nigeria.

2. Material and Methods

2.1. The Study Area [Niger Delta—Ebocha-Obrikom Geology]

Geographically the Niger Delta basin is one of the seven sedimentary basins in Nigeria. It is considered as the most significant owing to its petroliferous nature and consequent active hydrocarbon exploration and production operations occurring both onshore and offshore. The Niger Delta basin has three major formations namely, the Agbada, Akata and Benin Formations. The Benin Formation is the uppermost consisting of considerable amounts of non-sea sand predominantly sandstone together with deposits of gravels [60]. The formation contains negligible amounts of hydrocarbon [61]. The Agbada Formation lies beneath the Benin formation and overlies the Akata Formation. The formation encompasses reservoir rocks and seals [61]. The Akata Formation, which is at the base is about 7000 m thick and consists of basically clay and shale. The formation is rich in organic matter and is believed to be the major rock generating hydrocarbons in the study area.

The Ebocha-Obrikom area falls within the oil and gas hub of Nigeria, one of the major cities of the Niger Delta located in Rivers State and is placed between latitude 5˚20N - 5˚27N and longitude 6˚40E - 6˚46E is situated in Ebocha-Obrikom (see **Figure 1** below). It encompasses Obrikom, Obie, Obor, Ebocha as well as Agip New Base towns all located in Ogba/Egbema/Ndoni Area of Rivers State (**Figure 1**). The study research area lies to the North by River Nkissa, by the West, River Orashi, by the East, River Sombrero and by the South Omoku town [17] [18] [20] [21]. Significant changes in the land use/land cover in the area include changes in water bodies, built-up areas, depletion of the mangrove vegetation along rivers and creeks shorelines, vegetation, and wetlands. The mean temperature ranges between 30.0˚C - 33.0˚C, while the annual rainfall ranges between 2100 mm - 4600 mm as reported by Nigerian Meteorological Agency [62]. Also, it is located in a tropical wet climate with lengthy and heavy rainy seasons, rain water is unwholesome for drinking due to the presence of industries emitting noxious oxides into the atmosphere. The entire drainage pattern is greatly influenced by the combined hydrological effects of the Orashi River up North, the River Sombriero Eastwards and the St. Batholomew and Santa Barbara Rivers on the Southern and South-western end (**Figure 1**).

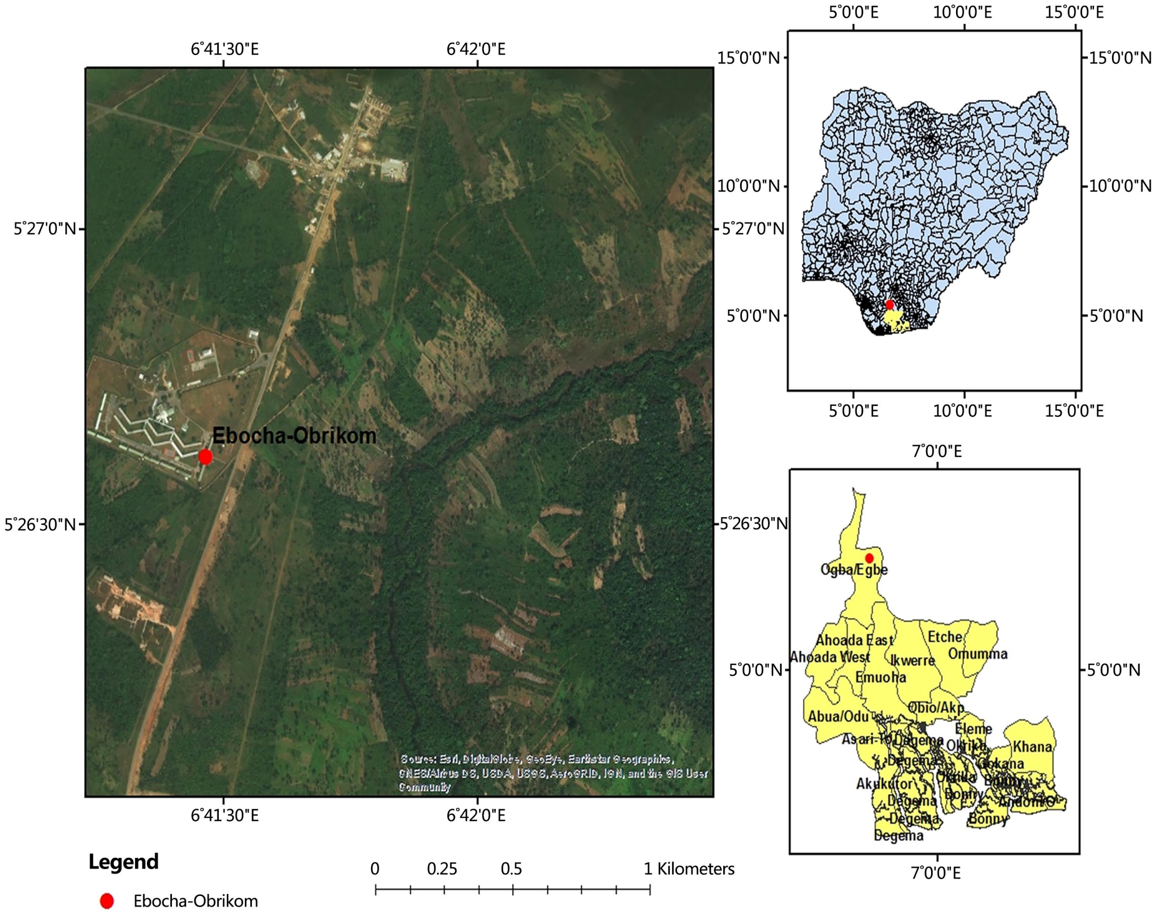

Figure 1. Map showing the study area with nigeria and river state insert. Sources: Adapted from Olalekan *et al.* [23] (https://doi.org/10.4236/ojogas.2018.33017).

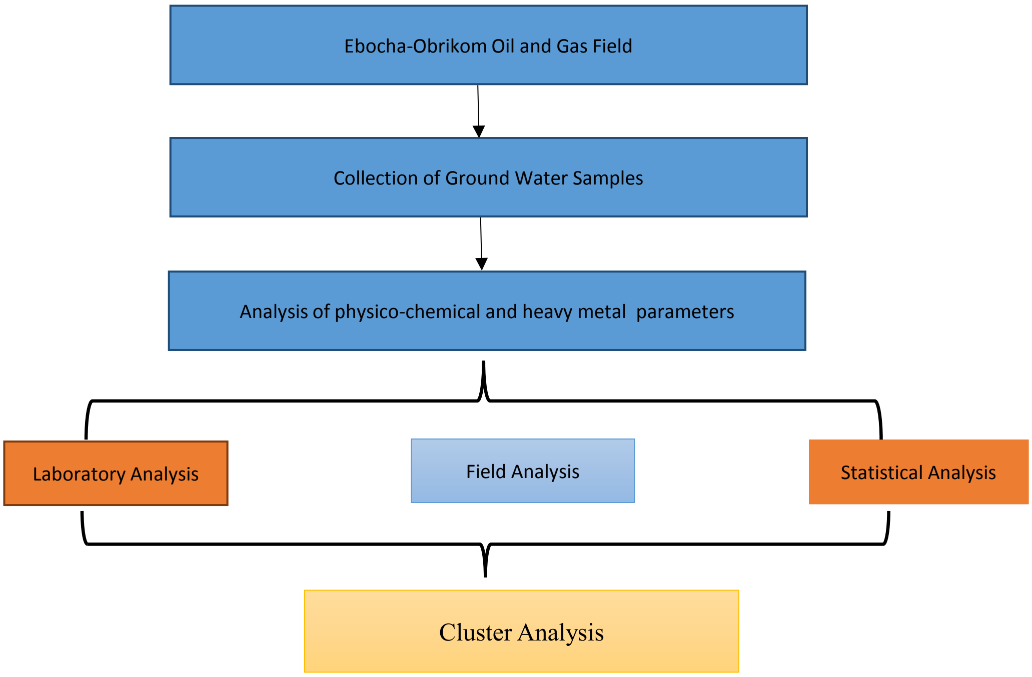

Figure 2. A schematic illustration of quantification methodology adopted for the current study.

2.2. Field Sample Collection

The sampling strategy employed for the current research investigation was similar to that utilized by Morufu and Clinton [25]; Raimi and Sabinus [24]; Olalekan *et al.* [23] in which sampling was targeted in some vulnerable quarters at a densely populated location. These quarters are places predisposed to all kinds of contamination not only because of their geographical situation but also because of the presence of crude petroleum exploration and exploitation. From the sample location (see Table 1 below), extracted water samples from groundwater sources utilized mostly for drinking as well as domestic activities. Sample collections were limited to only groundwater from dug wells or shallow pumping wells built for household uses exclusively. The depth of the wells varies between 10 to 28 m, which is a phreatic aquifer. The sampling locations sites were documented using portable GPS mobile devices. In the vicinity of the depot, ground water sources were selected randomly but at various distances from each other for the purpose of this investigation. Furthermore, the samples were manually collected from nine (9) strategic locations in the study area for ground water (boreholes and wells) into previously washed clean plastic sampling bottles after about 20 min of continuous water flow 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 a.m. to 4:00 p.m. As a result of instability, floods, and the COVID-19 shutdown, night samples were not taken, and the sampling took place from September 2019 to August 2020. The depth varied between 10 and 28 meters.

Table 1. Geographical coordinates of the nine (9) 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. 2500 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	(Control) (35,000 m from Ebocha)	-	Lat N5˚4'58.1412"	Long E6˚39'30.4806"

2.3. Sampling, Preservation and Analysis

The standard methods outlined in American Public Health Association (APHA) (2012) [63]; Morufu and Clinton [25]; Raimi and Sabinus [24]; Olalekan *et al.* [23] have been strictly followed by water sampling, conservation, transportation as well as analysis. In-situ measurements of the following parameters viz: temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved substance (TDS), turbidity and total dissolved solids (TDS) were carried out in the field using HANNA water quality checker [63].

2.4. Ground Water Collection

For the analyses of physico-chemical parameters, ground water samples were collected using pre-rinsed 1litre plastic containers. Pre-rinsed ground water samples for heavy metal analyses were collected with nitric acid of 1litre containers as well as treated with 2 ml nitric acid (assaying 100%, Trace Metal Grade, Fisher Scientific) prior to storage. These were done to stabilize the metals oxidation conditions. Groundwater samples were collected in two groups of 250 ml glass-stoppered-reagent bottles per sampling location for Biological Oxygen Demand (BOD), and Dissolved Oxygen (DO) determinations. The BOD samples have been properly filled without air trapping as well as the bottles are covered in black polythene bags. This was done to eliminate light, which is present in the samples and capable of producing DO by autotrophes (algae). The BOD samples were incubated for five days, which was added to 2 ml of each sample. In order to retard additional biological activities, Winkler solutions I and II use different dropping pipettes for each sample. The bottles were thoroughly shaken to precipitate the floc, which lay at the bottom of the bottles. Further, Winkler solution I is a solution of manganese sulphate, while solution II is sodium or potassium iodide, sodium or potassium hydroxide, sodium azide (sodium nitride) and sodium hydroxide. The DO samples were collected in clear bottles and also tightly stoppered. With samples of dissolved oxygen preserved on the spot with Winkler I and II solutions similar to that of the BOD samples [63]. All samples had been clearly identified and controlled at 4˚C for easy identification. Determination was carried out on site to know the concentrations of unstable as well as sensitive water quality characteristics including total dissolved solids (TDS), electrical conductivity (EC), pH, alkalinity (Alka.), and temperature (Temp). Thus, the fundamental approaches for investigating the groundwater composition are described in **Figure 2** above.

2.5. Quality Assurance and Quality Control (QA/QC)

Furthermore, using high purity analytical reagents and solvents, all analytical operations were thoroughly monitored using quality assurance and control methodologies. The instruments were calibrated using calibration standards. The analytical technique validation included the use of procedure blanks, triplicate analysis, as well as the examination of certified reference materials (CRM). The limit of detection (LoD), repeatability, precision, reproducibility, as well as accuracy of each organic contaminant in groundwater samples was determined.

3. Results

The cluster diagram in **Figure 3** and **Figure 4** show the grouping of heavy metal in the study area wet and dry season. **Figure 3** reveals that 5 distinct clusters were identified with the following heavy metals in each of the cluster, cluster 1: Cl, Cluster 2 comprised of Ca, Cluster 3 comprised of F, Al, K, Fe, Zn, Mn, Cd, Pb, Cu, Cr, SO_4, NH_3, PO_4, NO_2, NO_3, Ni and TPH. Only two heavy metals were classified into cluster 4 (Na and TPH) while cluster 5 was made of Mg. During dry season as presented in **Figure 4**, 4 clusters were identified with Cl in Cluster 1, Ca in cluster 2, F, Al, K, Na, Fe, Zn, Mn, Cd, Pb, Cu, Cr, SO_4, NH_3, PO_4, NO_2, NO_3, Ni and TPH in cluster 3 while cluster 4 comprised of only Mg.

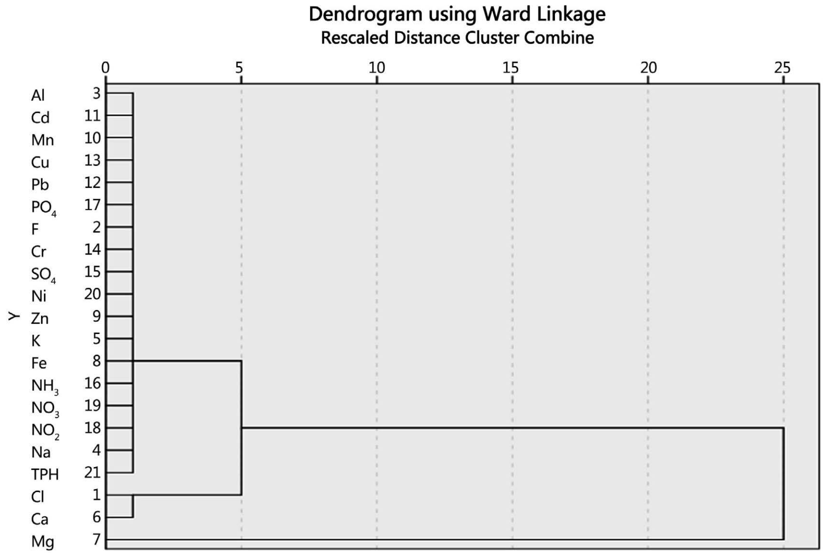

Figure 3. Chemical component-wise cluster shown for heavy metals and chemical ions in dendrogram during rainy season.

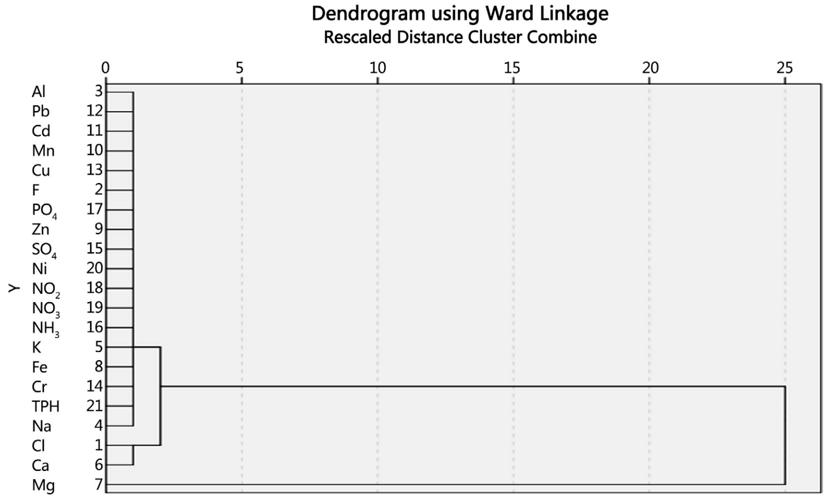

Figure 4. Chemical component-wise cluster for heavy metals and chemical ions shown in dendrogram during dry season.

The cluster diagram in Figure 5 and Figure 6 reveals the grouping of physicochemical parameters in the study area wet and dry season. Figure 5 reveals that 5 distinct clusters were identified with the following physicochemical parameters in each of the cluster, cluster 1: alkalinity, hardness, in cluster 2, it was conductivity, DO, COD and acidity was in cluster 3, pH, turbidity, BOD, TDS, salinity were in cluster 4 while temperature and TSS were in cluster 5. For dry season (Figure 6) with 4 distinct 4 clusters with alkalinity in cluster 1, pH, turbidity, DO, BOD, TDS, salinity in cluster 2, conductivity and acidity in cluster 3 and temperature, COD, hardness and TSS in cluster 4.

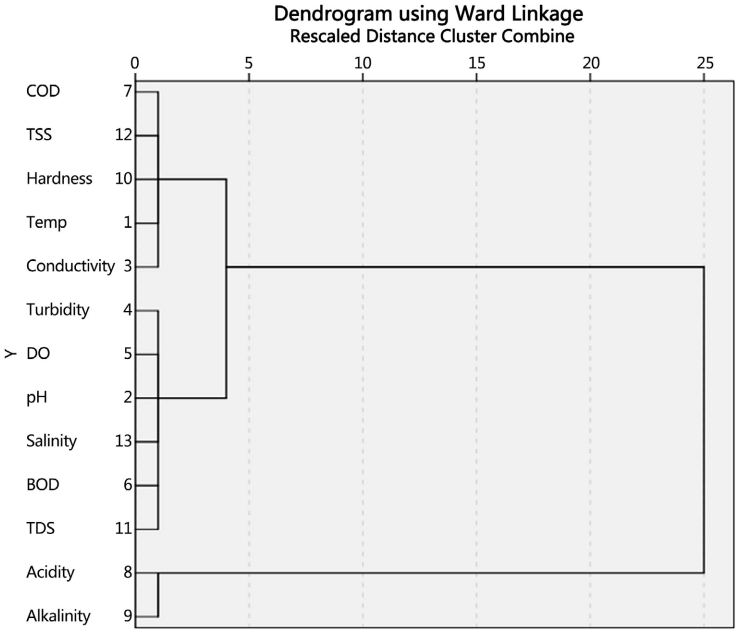

Figure 5. Chemical component-wise cluster for physicochemical parameters shown in dendrogram during wet season.

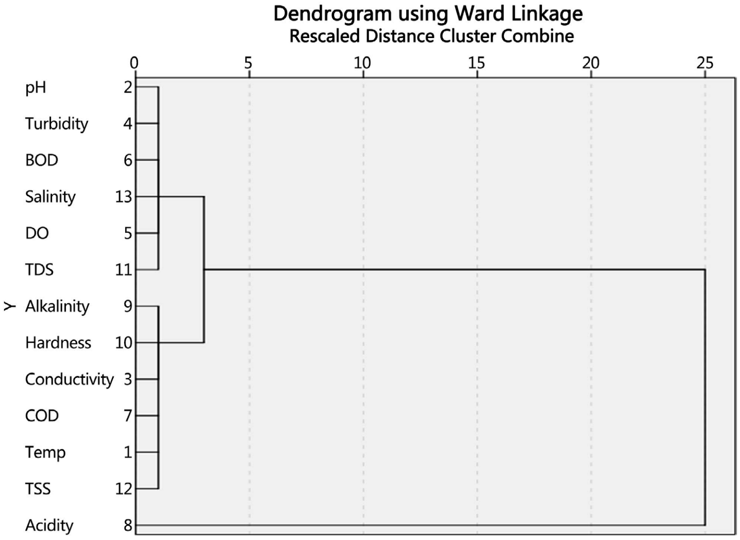

Figure 6. Chemical component-wise cluster for physicochemical parameters shown in dendrogram during dry season.

4. Discussion

Hierarchical Cluster Analysis (HCA) of Groundwater Chemical Variables

Because of inherent toxicity, endurance, and bioaccumulation, heavy metals are the most frequently occurring substances in the environment [64] [65]. Heavy metals (lead (Pb), nickel (Ni), chromium (Cr), mercury (Hg), arsenic (As), cobalt (Co), cadmium (Cd), zinc (Zn), and copper (Cu)) have a significant toxicity even at low quantities [17] [18] [66]. These contaminants are produced by both human-made as well as natural processes [17] [18] [23] [67]. Industrial, agricultural, mining, and metallurgical operations are examples of anthropogenic activities that result in the emission of heavy metals as well as other pollutants. Automobile exhaust, smelting, pesticides, as well as fossil fuel combustion are all factors which contribute to heavy metal pollution, including selenium, arsenic, lead, zinc, copper, vanadium, nickel, mercury, and tin [67]. Sea-salt sprays, volcanic eruptions, forest fires, and wind-borne soil particles, on the other hand, are all natural sources of these metals. Another source of heavy metals discharged into the atmosphere is rock weathering [68]. Several investigations have shown that elevated amounts of heavy metals are caused by natural emissions including traffic-related vehicle exhaust [69] [70]. Environmental pollution as well as heavy metals' eventual harmful impact are a serious ecological and public health problem [17]-[25] [71]-[77]. Despite the fact that several heavy metals constitute important micronutrients for a variety of biochemical and physiological processes as well as activities [17] [18] [23] [24] [25], high levels of exposure to these agents causes a variety of health problems and disorders [11] [12] [16] [78]. Each metal has its own toxicological profile as well as method of action. These toxicological consequences are dependent on the age, gender, heredity, and nutritional state of those who have been exposed. Given their systemic toxicity as well as carcinogenic effect on the population, limiting access to arsenic, cadmium, arsenic, chromium, lead, and mercury is a public health concern [17] [18] [79]. Therefore, clustering analysis is used for grouping water quality parameters or sampling locations by looking at similarities in their chemical compositions and their interdependency. It is a multivariate technique for analyzing correlation coefficients to obtain similarity coefficients and plot a dendrogram. The cluster tree connects the subjects of the same weight to create larger clusters and assess similarities between specimens [80] [81] [82] [83] [84]. In order to establish probable correlations among the examined parameters, a Cluster analysis using the Ward correlation approach was done. Thus, the categorization of the data set into different groups primarily depends upon the homogeneity or non-homogeneity among the data sets. This examination was first used to assemble the hydrogeochemical parameters dependent on their mean likenesses. In this analysis, Ward's method and Euclidean distance were used to obtain clustering of samples. The computed results of HCA of groundwater samples was used also to find groups among metal based on Square Euclidian Distance (SED) [83] [85]

[86]. The results of spatial distribution of the hierarchical cluster analysis (HCA) of chemical variables in groundwater from the study area are presented in dendrogram (**Figures 3-6**). Sampling records from the same region are generally assigned to the same cluster during HCA. The cluster diagram in **Figure 3** and **Figure 4** show the grouping of chemical ions and heavy metal in the study area for wet and dry season. **Figure 3** reveals that 5 distinct clusters based on the similarity that were identified with the following heavy metals in each of the cluster, cluster 1: Cl, Cluster 2 comprised of Ca, showing that metals in cluster 1 and 2 are from human activities, mainly from influence of anthropogenic source in the area. A similar observation was also made during the dry season, showing Cl and Ca belonging to cluster 1 and 2. Calcium is the dominant ion, thus, the occurrence of groundwater in Group 2 is considered as a natural chemical quality of groundwater for evaluating the various sources in the other groups. Cluster 3 comprised of F, Al, K, Fe, Zn, Mn, Cd, Pb, Cu, Cr, SO_4, NH_3, PO_4, NO_2, NO_3, Ni and TPH, indicating secondary origin. They are produced from precursors arising from diverse gas flaring processes, particularly petroleum hydrocarbons.

Also, they all come from similar sources, specifically natural sources as well as anthropogenic sources, which is consistent with the enrichment factor (EF). The results indicate that urbanization, extractive industry activities and agriculture development in this area have influenced the mobilization of heavy metals (*i.e.*, Fe and Pb) in the ground water. In addition, it signifies that the contamination of sampling locations is mainly due to anthropogenic factor such as industrial effluents, leachates from overburden materials and mining waste, industrial wastewater, urban waste and sewage activities, along with seasonal variations [15] [87]. The Cluster 3 is expected due to influences of both the geogenic processes (weathering as well as dissolution of minerals, ion exchange between Ca^{2+} and Na^+, and anthropogenic sources (domestic wastes, irrigation-return flow and chemical fertilizers) on the groundwater system. As a result, the groundwater is characterized by the variable stated above. This indicated that metals in the third cluster could have come from a variety of geogenic as well as anthropogenic sources such as organic pigments in plastics, atmospheric deposition from gas flaring as well as burnt biodegradable wastes. Thus, third cluster has majority of all the factor parameters, which account for a distinctive characteristic in regard to the evaluated ions. This demonstrates a blended genesis connected to anthropogenic and geogenic measures. The cluster distribution has a link to physiognomy and geology tectonics, which might lead to distinct hydrochemical reactions. As a result, distinct types of groundwater are formed by the lithology of the bedrock and related soil. Furthermore, tectonic features, particularly faults, regulate stratum distribution and geomorphology, which is linked to various kinds of groundwater [17] [18]. Aquifers may not be continuous in the same unit due to the effect of geological structure. Therefore, Cluster 3 is considered as pollution-controlled cluster. Only two heavy metals were classified into cluster 4 (Na and TPH) while cluster 5 was made of Mg. These clusters suggest that there are five (5) distinct sets of influences that affect the groundwater samples. They are salinity, carbonate hardness and pollution processes, respectively. During dry season as presented in **Figure 4**, 4 clusters were identified with Cl in Cluster 1, Ca in cluster 2, this cluster can be attributed to a single factor due to influence of natural processes of weathering of calcium and magnesium minerals present in the country rocks and dissolution of soil CO_2 in the groundwater system [4] [5] [17]-[25]. F, Al, K, Na, Fe, Zn, Mn, Cd, Pb, Cu, Cr, SO_4, NH_3, PO_4, NO_2, NO_3, Ni and TPH in cluster 3, showing a notable distinction between clusters 1 and 2. The following are the reasons behind this. To begin, the weathering of Cluster 3 principal hydrochemical process. Second, the lower water level of the aquifer renders the Ebocha-Obrikom region more susceptible to contamination than other areas. Water quality in shallow water depth places has previously been challenged by nitrate pollution from agricultural infiltration, which also affects water chemistry. Furthermore, cluster 3 exhibits a direct ionic exchange mechanism and is concentrated on a populated region. In addition to agriculture, industrial activities such as gas flaring and domestic activities have an impact on the aquifer, resulting in variances across clusters during wet and dry seasons. Thus, all this is mainly controlled by the geogenic factor and can be corresponded with mineral dissolution and rock-water interactions which regulate the characteristics of groundwater in the study area [88]. While cluster 4 comprised of only Mg. For the physicochemical parameters that had similar characteristics were grouped using dendogram Hierarchical cluster [89]. The parameters were distinctively grouped into clusters and the cluster diagram in **Figure 5** and **Figure 6** reveals the grouping of some physicochemical parameters in the study area for wet and dry season. **Figure 5** reveals that 5 distinct clusters were identified with the following physicochemical parameters in each of the cluster, cluster 1: alkalinity, hardness, this TH is a combination of Ca^{2+} and Mg^{2+} ions, it is considered as a result of total dissolution of all ions, which gives information on the hardness and degree of quality of groundwater, reflecting a wide variation in geochemical processes prevailing in the present study area. Therefore, Cluster I is considered as alkalinity and hardness-controlled cluster. In cluster 2, it was conductivity, DO and COD, showing a result of decaying organic matter and root respiration, which in turn, combines with recharge water. The higher concentration of conductivity, DO and COD infers a dominance of organic matter and mineral dissolution [90]. Thus, Cluster II is considered as conductivity, DO and COD controlled cluster, acidity was in cluster 3, pH, turbidity, BOD, TDS, salinity were in cluster 4, thus, affirming the solid relationship between the correlation analysis factors. Additionally, this is in accordance with the perception that the TDS has medium to high relationship with those parameters specific to anthropogenic/farming sources (pH, Conductivity, BOD, Acidity, Hardness), furthermore, water-rock contact occurs continually along the groundwater flow channel, resulting in mineral breakdown and the release of ions and oxygen elements into the groundwater, resulting in TDS enrichment.

Physical and chemical characteristics are predicted to enhance its content (**Figure 5** and **Figure 6**), contradicting evolution rules. Furthermore, if the elevated TDS is due to increased water-rock interaction, other physicochemical parameters should rise as well. However, data analysis reveals that values in all clusters are comparable. While temperature and TSS were in cluster 5. These clusters suggest that there are five (5) distinct sets of influences that affect the groundwater samples. They are salinity, carbonate hardness and pollution processes, respectively. Thus, temperature and TSS are in separate group while the rest of the parameters are in other groups. The variations in the type of parameter grouped into different cluster could be associated with the differences in sample source, which were affected by the nature of activities around it, and the concentration of the parameters in the groundwater sample. The cluster showed that conductivity, DO, COD and Alkalinity are not influenced by any other parameters analyzed, while pH is influenced by Turbidity, BOD, TDS and Salinity of the groundwater sample.

For dry season (**Figure 6**) with 4 distinct 4 clusters with alkalinity in cluster 1, pH, turbidity, DO, BOD, TDS, salinity in cluster 2, conductivity and acidity in cluster 3 and temperature, COD, hardness and TSS in cluster 4. Group two, which comprises pH, turbidity, DO, BOD, TDS, salinity except parameters in group 1, 3 & 4, influenced one another, which was in line with the observation of Radha-Krishnan *et al.* [91], Praveen *et al.* [92]; Oparaocha *et al.* [93] and Basamba *et al.* [94] which attribute concentration of Ca to anthropogenic activities and natural processes within the aquifers as major sources of groundwater hardiness. Thus, the present study indicates the influence of anthropogenic origin on the aquifer chemistry [95]. Therefore, the excess concentrations of various physicochemical parameters along the cluster 1 & 2 compared with those of cluster 3 & 4 obviously indicate the water-rock-interaction as the dominant controlling process and the anthropogenic origin as an additional source on the groundwater body. These findings are largely consistent with previous studies from around the world. Governments, social organizations, and international scholars have paid close attention to recent and increasingly intense anthropogenic activities, like mining [98], land creation [99], urbanization [96], industrialization [13] [97], and cultivation [100] [101] [102], as well as their environmental impacts. The consequences on groundwater remain major among the many environmental repercussions of anthropogenic activities [17]-[25]. To assist scientific groundwater management, several groundwater quality investigations have indeed been undertaken in the core Niger Delta [17]-[25] [43] [44]. In the Weining Plain, an arid as well as semiarid region in northwest China where groundwater has been impacted via industrial and agricultural activities, Li *et al.* [103] investigated groundwater quality and its implications on human health. The study looked into the hydrogeochemistry, general groundwater quality, irrigation suitability, and possible health hazards associated with nine pollutants in groundwater (F^-, NH_4^+, NO_2^-, NO_3^-, Cu, Mn, Zn, As, and Cr^{6+}). The research provides a theoretical foundation for scientific groundwater management and usage. Also, Wu *et al.* [104] investigated the origins of groundwater contamination and their influencing variables in and around Yan'an Metropolis, China, a rapidly rising city on the Chinese Loess Plateau. That investigation pinpointed the sources of toxins in Yan'an City's groundwater, which is crucial for long-term groundwater preservation. Thus, all these differences in the various chemical parameters could be due to influence of pollution activity caused by anthropogenic (irrigation-return-flows, chemical fertilizers and domestic wastes) sources on the existing groundwater quality of the geogenic origin (water-rock-interactions linked with mineral weathering as well as dissolution, ion exchange and evaporation are all involved). Thus, this established fact indicates that the controlling processes of geochemistry of groundwater lead to contamination of groundwater. Thus, the identical combinations of water parameters obtained in PCA and CA confirm that the groundwater quality and characteristics are strongly influenced by natural process as well as anthropogenic factors.

5. Conclusion and Implications of the Study

In addition to the human and environmental consequences, groundwater contamination has a monetary cost in the billions of Naira. As a result, precise and reliable data on groundwater pollution is critical for promoting social health initiatives in Nigeria's oil-rich Niger Delta. The intake of water polluted with physicochemical characteristics might provide a health concern to local residents and surrounding consumers, since drinking water is one of the ways of human exposure to a variety of components. Thus, early monitoring of human sensitivity to environmental pollution is critical for fast action to minimize pollution as well as, the negative health impacts. To regulate and forestall heavy metal toxicity, national collaboration is required to develop successful strategies, policies, and practices through coordinated engagement with all stakeholders in order to achieve an integrated as well as holistic implementation. The present study has successfully carried out an overall suitability assessment by grouping ground water heavy metals parameters into similar groups in the Ebocha-Obrikom Area of Rivers State Nigeria using an integrated Hierarchical Cluster Analysis (HCA) approach. It was found that the quality of water within the study area is degraded owing to elevated levels of heavy metals (such as Cd and Pb); thus, these metals are seen as the main influencers of the poor drinking water quality. Therefore, the data obtained in the present study could be useful in comparing groundwater resources in oil rich Niger Delta region of Nigeria with groundwaters in different parts of the world. The following highlights are offered after the broad research findings:

- Chemometric analysis unveiled that the variation in the hydro geochemistry and water quality within the study area is mainly a result of the influence of both geogenic (weathering and dissolution of silicate and carbonate minerals) and anthropogenic activities such as oil spillage, agricultural and gas flaring activities, which play significant roles in groundwater contamination by physicochemical and heavy metals in the study area. Thus, as it is likely that physicochemical and heavy metals will increase in the groundwater in the future, it is suggested that more research be done to establish the effect of heavy metal bioavailability.

- Ensure the mandatory implementation of a detailed Environmental and Health Impact Assessment in the Niger Delta region of Nigeria, while also introducing stringent quality standards for various oil and gas operations.
- Ensuring that remedial measures toward mitigating the negative impact of the oil and gas industry are built into the industry creating shared value.
- Implement post environmental audits that ensure that the in-built mitigating measures satisfactorily address the anticipated environmental and public health concerns.

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Availability of Data and Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Supplementary Material

The Supplementary Material for this article can be found online at: Raimi, Morufu (2021): Water Quality Parameters in Gas Flaring Area of Ebocha-Obrikom of Rivers State, Nigeria. Figshare: Dataset.
https://doi.org/10.6084/m9.figshare.14273234.v1;
https://figshare.com/s/c7f5d0e75e096a20a8e1.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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List of Abbreviation

˚C—Temperature
pH—Hydrogen Potential
NTU—Nephelometric Turbidity Unit
DO—Dissolved Oxygen
BOD—Biological Oxygen Demand
COD—Chemical Oxygen Demand
TH—Total Hardness
TDS—Total Dissolved Solids
TSS—Total Suspended Solids
Cl—Chloride
F—Fluoride
Al—Aluminum
Na—Sodium
K—Potassium
Ca—Calcium
Mg—Magnesium
Fe—Iron
Zn—Zinc
Mn—Manganese
Cd—Cadmium
Pb—Lead
Cu—Copper
Cr—Chromium
SO_4^{2-}—Sulphate
NH_3^-—Ammonia
PO_4^{3-}—Phosphate
NO_3^-—Nitrite
NO_2^-—Nitrates
Ni—Nickel
TPH—Total Petroleum Hydrocarbon
mg/l—Milligrams per liter
APHA—American Public Health Association