# Groundwater Geogenic and Anthropogenic Assessment of Organic and Inorganic Contaminants within Three Major Metropolies in Enugu

Ezeh Uchechukwu A and D. C Ozoko
Department of Geology and Mining,
Faculty of Applied Natural Sciences Enugu State University of Science and Technology

**ABSTRACT**
This study assessed the impact of increased industrialization and population within three major metropolis in Enugu, namely Abakpa, Emena, and Independence Layout by analyzing 60 water samples and 10 shale samples. Inventory of Dumpsites were done and categorized into domestic, industrial, commercial and hazardous wastes. Pollution load indices analysis such as Heavy metal pollution index (HPI), Heavy metal evaluation index (HEI) and Degree of contamination ($C_{deg}$) categorized the groundwater quality in the study area into low, intermediate and high contamination. The multivariate statistical analysis extracted three anthropogenic diagnostic factors controlling the chemistry based on the parameter associations. The XRD analysis shows that influence of geogenic factors in groundwater contamination within the study area is very minimal. None of the computed WQI fell within the excellent water quality within the stud. Generally 28.3% of the groundwater fell under the good water quality, 41.6% within the poor water quality, 20% within the very poor water quality and 10% within the unsuitable water condition.
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## 1.INTRODUCTION

Human health is negatively impacted by poor environmental conditions, which can also result in significant financial loss. Careless, intensive industrial expansion has a greater negative influence on the environment, and this is especially true in the largest industrial cities. The environment is crucial for the expansion and sustainability of life. The US Environmental Protection Agency has named heavy metal pollution as one of the top pollutants caused by rising industrialization and urbanization. Organic micro pollutants and heavy metals (As, Cd, Pb, Cr, Cu, Hg, and Ni) are reportedly the most prevalent heavy metals found in polluted environments (Adelekan and Abegunde 2011). Production of heavy metals roughly doubled between 1850 and 1990. (Nriagu et al. 1996).

Anthropogenic activity on groundwater quality are governed by the physical and geochemical processes, as well as the hydrogeological state present. Groundwater quality is a function of both geogenic processes and anthropogenic activities (Sajad et al., 1998). Studies that look at groundwater quality in connection to the influence of geology become essential since groundwater originates through pores and/or cracks in geological formations. This study's aim is to assess the level of organic and heavy metal contamination in groundwater in three settlement zones in Enugu city, southeast Nigeria (Abakpa-Nike, Emene, and Independence Layout).

The Anambra Basin, which was created following the Santonian tectonic deformation, is located southeast of the Enugu metropolis (Nwajide and Reijers, 1996). Shales from the Campanian-Maastrichtian-aged Enugu Formation underlie the city and the most of its suburbs (Onuoha, 2006). Groundwater continues to be the city's primary source of water supply because so many citizens rely on water from manually dug wells for household purposes (Ekwe et al., 2006; Eze, 2011). Many subsurface fissures underlying the land and heavy rainfall are two hydrogeologic factors that favor groundwater in the study area (Uma, 2003). The city has seen an increase in water consumption for more than twenty (20) years due to population growth, but there hasn't been a corresponding increase in water supplies, particularly in Abakpa, Emene, and Independence Layout.

### 1.1LOCATION OF THE STUDY AREA

The study area, covering 191.19 km$^2$is located within Enugu metropolis in southeastern Nigeria (Fig. 1a). The area is bounded by latitudes 6°24' and 6°31' north of the equator and longitudes 7°29' and 7°37' east of the Greenwich meridian (Fig. 1b). It has a network of both secondary and primary roads. The primary roads connect major towns within the metropolis while the secondary roads link the local communities to the primary roads. There are minor pathways and access routes that traverse the area. A major railway, which links the southwestern part of the area to the northeastern region, is seen passing through Independence Layout and Emene.

Generally, the area is accessibile through major paved roads that link the study area to the southern part of the country through Awka and Onitsha, and the northern part through Nsukka and Obollo-Afor. Other major paved roads connect the study area to the commercial areas in Ninth Mile. Majority of the roads are seasonal, and several of them are relatively passable in the heart of the rainy season (June - September). The surrounding villages and towns are Nsude, Oji River, Obioma and Udi to the south; Nsukka, Ameke Ngwo to the north; Abaja Ngwo, Ngwo Uno, Uwani Uborji to the northeast, and Eke to the northwest.

The Enugu Formation, which consists of blue to dark grey and soft grey shales and mudstones, underlies the city in the majority. The shale units also contain interbedded sandstones and sandy shales (Reijers, 1996). The fractured shales have a history of weathering into grayish and blackish laterites that operate as a cap over the bedrock and, in certain places, can reach a thickness of roughly 20 m. (Onwuka et al., 2004). One of the known aquifers in the city that is normally continuous but occasionally interrupted by new bedrock is made up of the fractured parts of the shale. The sandstone aquifers in Agbani and Owelli are two others (Ezeh, 2020). Precipitation provides aquifer replenishment.(Fig 2).

Regionally, the study area is characterized by a north-south trending escarpment (cuesta) that crosses the area. The cuesta represents a major sub-surface and surface water divide for two drainage (hydrogeological) basins (Anambra River and Cross-River basins). The study area is located between the crest (gentle upper slope) of the cuesta and the foot of the scarp. The eastern part has a lower relief (100-140 m) whereas the western part has a higher relief (>200 m).The area receives numerous fast flowing second to third order rivers and streams from the surrounding areas. The drainage pattern is dendritic, with mostly Traverse Rivers draining into a major river that flows from west to east. The Nyaba River is the largest river that drains the study area. It flows from west to east within the central and southern part of the study area with numerous tributaries (Fig 2).

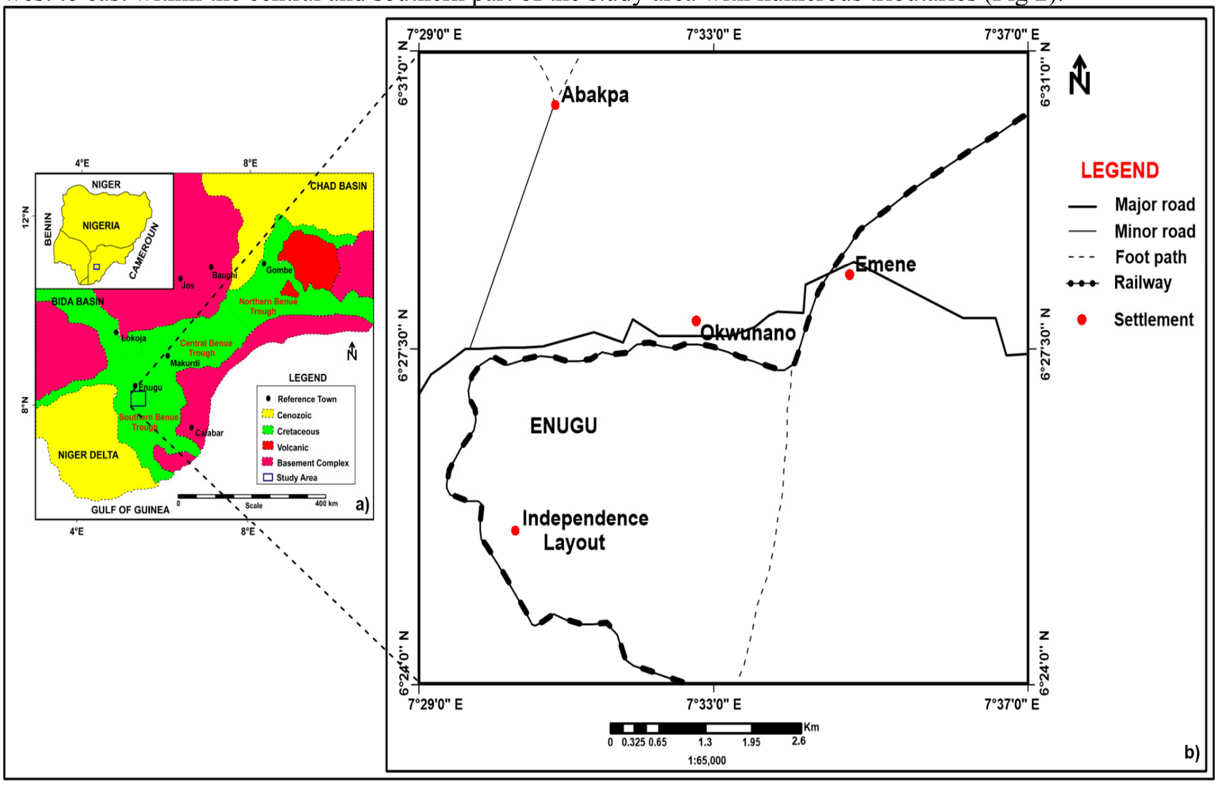


Fig. 1 (a) Regional geological map of southeastern, north-central, and northeastern Nigeria showing the location of the study area (Amobi et al., 2021) (b) Map of the study area showing various access routes within the area

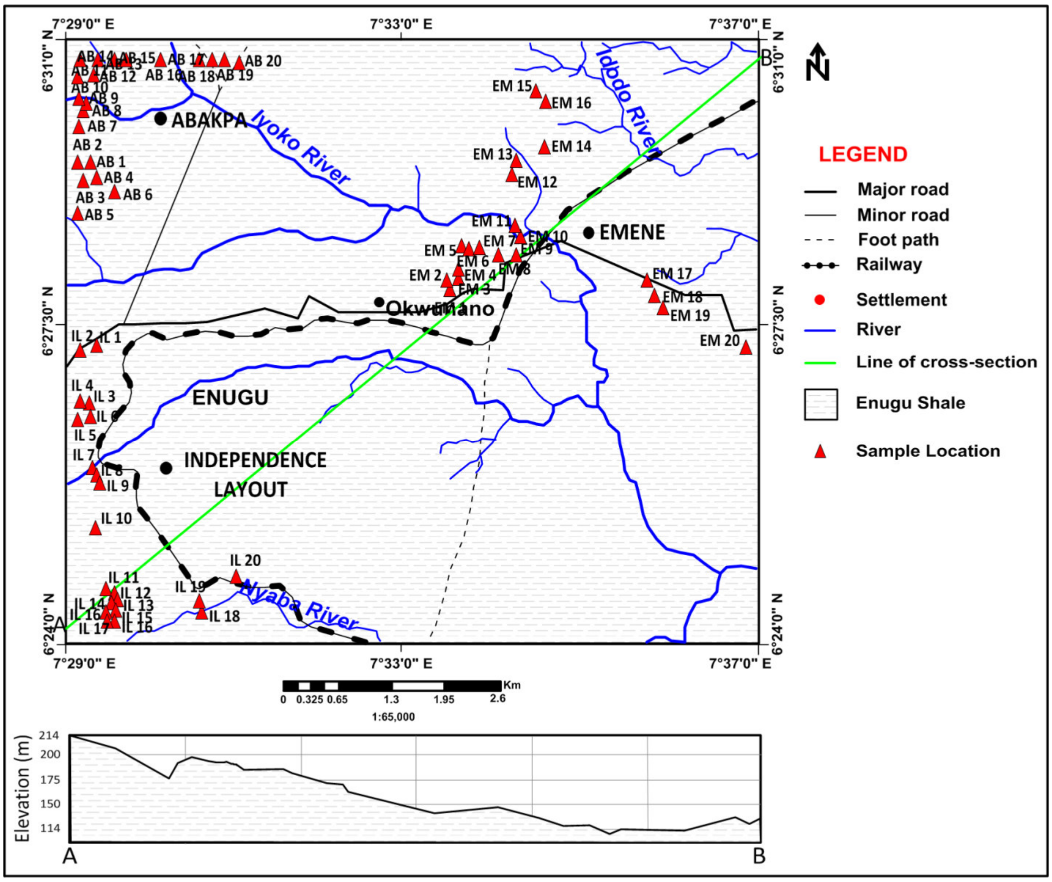


**Fig. 2** Geologic map of the study area showing the drainage pattern and sampled locations

## 2.METHOD OF STUDY

This study started with a desk study and reconnaissance survey. A reconnaissance field study was conducted between 12th and 14th of March, 2022 to identify the locations of dumpsites, sewage systems, timber markets, and oil spill zones in three settlement areas (Abakpa, Emene and Independence Layout) within the metropolis prior to the sample collection. The focus of the field study is to identify and sample groundwater which are proximal to dumpsites, sewage systems, timber markets and oil spill zones Groundwater samples were collected from hand dug wells and boreholes at sixty (60) different points within the three settlement areas (i.e. twenty (20) samples were taken from each settlement area). Of the 60 samples, three (3) samples (one (1) from each area), collected away from the source points, were designated as control samples. 10 shale samples were collected to assess the impact of rock mineral on groundwater chemistry. The concentrations of heavy metals and the presence of organic compounds in water samples collected from three settlement areas (Abakpa-Nike, Emene and Independence Layout) in Enugu metropolis, Nigeria has been assessed using physicochemical, HPLC-MS (High Performance Liquid Chromatography coupled to Mass Spectrometry) and contaminant transport modeling techniques.

The work flow summarizes the systematic steps taken in this research (Fig 3)

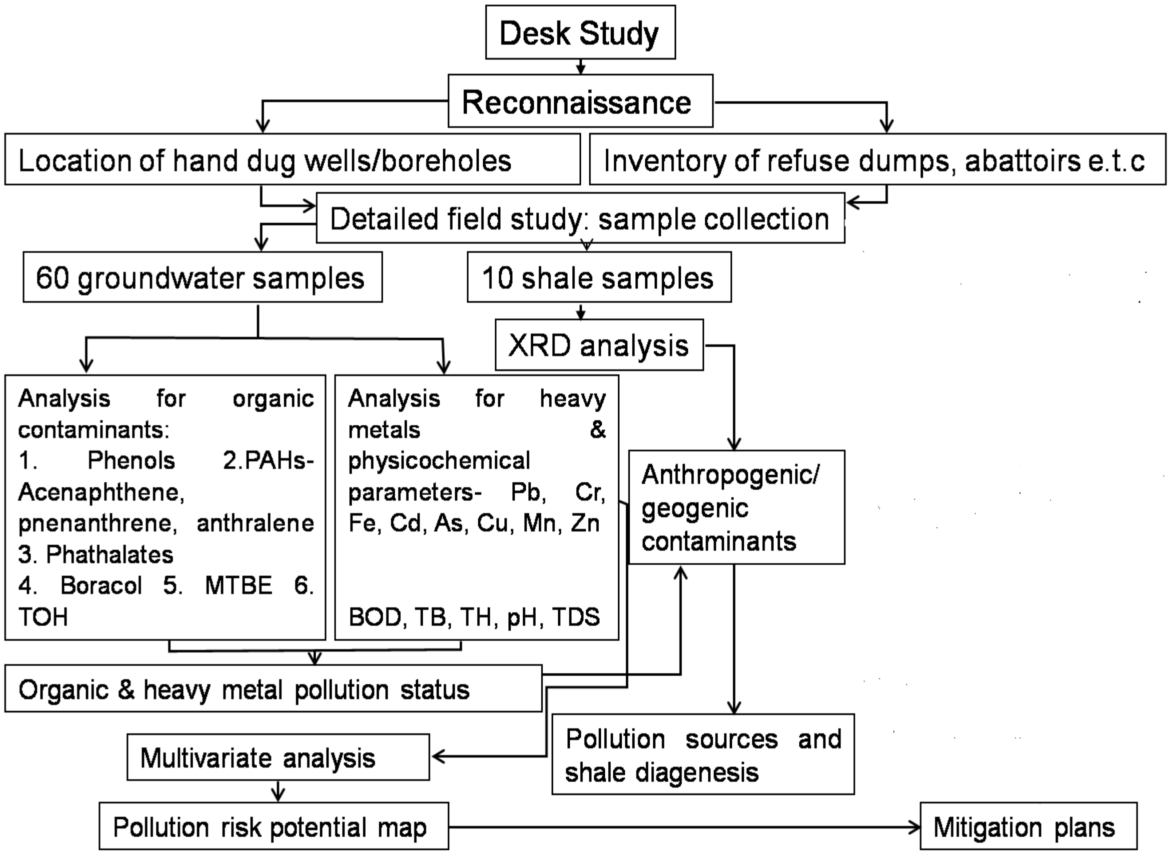

**Fig. 3** Adopted workflow for the study showing the methods applied

## 3.RESULTS AND DISCUSSION

### 3.1Description of the Present Status of Waste Management in the Study Area

The current state of waste management in the study region is outlined in this part, along with a thorough analysis of the various waste streams. The research area's open garbage dump sites were visited in the field, and the reports show that the area's wastes are currently not being managed appropriately The various trash containers, such as drums and bins, are insufficient and cannot hold the high volume of municipal solid wastes that are produced every day in the areas, in addition to being located close to residential areas. Due to this, parts of the waste materials were discovered scattered throughout neighboring roads and streams as well as far from the rubbish dump sites **(Table 1)**. The littering of wastes in the locations has also been made worse by waste pickers' activities. Domestic rubbish burning (open burning) is a common activity among inhabitants and waste pickers in all settlement areas, but it is especially prevalent in Abakpa. This behavior pollutes the air, reducing visibility and endangering motorists.

**Table 1** Inventory of the locations, names, estimated perimeter and area coverage of dumpsites in the three settlement areas within the study area

| Settlement Area | Name/Location of Dumpsite | Estimated Perimeter (m) | Estimated Area Coverage ($m^2$) | Dominant Waste Types |
|---|---|---|---|---|
| Abakpa | 1st Bus-stop | 260 | 4200 | domestic, commercial, industrial and hazardous |
| | Obinagu | 200 | 2500 | domestic, commercial and industrial |
| | Mmeriocha | 110 | 750 | domestic and commercial |
| Emene | Rehab Road | 100 | 625 | domestic, commercial and industrial |
| | Town School Road | 120 | 900 | domestic and commercial |
| | Orie Market | 92 | 529 | domestic, commercial, industrial and hazardous |
| Independence Layout | Maryland | 112 | 784 | domestic, commercial and industrial |

 

### 3.2 Groundwater Pollution Indices

In a holistic attempt to unravel the extent of groundwater pollution with the study area, four major techniques were employed namely degree of contamination (also known as contamination index) ($C_{deg}$), heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and Water Quality Index. The analyzed heavy metals (Cu, Fe, As, Ni, Pb, Cd, Cr, Zn, and Mn) were used in calculating the first three indicators, while the WQI involves integrating all the analyzed parameters.

### 3.3 Degree of contamination ($C_{deg}$)

The degree of heavy metal contamination within the study area was determined following the laid down procedures outlined by previous researches such as Jones-Lee and Lee (1993), Flyhammar (1995), Christensen et al. (2001), Kjeldsen et al. (2002), Oygard et al. (2004), Mor et al. (2006), Oman and Junestedt (2008), Vasanthavigar et al. (2010), Cumar and Nagaraja, (2011), Edet and Offiong (2002), Ezugwu et al. (2019) and Egbueri (2020). The summarized results are shown in Table.The permissible range of comparison for Cdeg is high (Cdeg> 80), medium (Cdeg = 40–80), and low (Cdeg< 40) (Edet and Offiong, 2002; Ezugwu et al., 2019; Egbueri, 2020).All the computed Cdeg for all the samples fell under the low contamination range (Cdeg< 40) with a general average value of 12.2788 (Figs 4 and 5).

**Table 2** Groundwater pollution indices (* represents control sample)

| Sample | Cdeg | HPI | HEI | WQI |
|---|---|---|---|---|
| AB 1 | 5.965 | 0.945 | 12.709 | 404.911 |
| AB 2 | 10.215 | 2.923 | 12.011 | 204.430 |
| AB 3 | 9.365 | 2.762 | 9.793 | 806.198 |
| AB 4 | 15.319 | 5.375 | 21.943 | 204.367 |
| AB 5 | 16.467 | 6.283 | 20.143 | 204.391 |
| AB 6 | 10.301 | 6.943 | 22.326 | 203.413 |
| AB 7 | 8.403 | 1.570 | 21.609 | 402.971 |
| AB 8 | 6.970 | 6.367 | 23.041 | 77.207 |
| AB 9 | 18.751 | 0.955 | 24.293 | 99.685 |
| AB 10 | 8.887 | 2.933 | 20.707 | 204.615 |
| AB 11 | 7.720 | 2.772 | 22.526 | 77.337 |
| AB 12 | 10.987 | 5.385 | 18.191 | 138.490 |
| AB 13 | 15.839 | 6.293 | 14.343 | 164.518 |
| AB 14 | 26.468 | 6.953 | 16.945 | 206.007 |
| AB 15 | 10.372 | 1.580 | 13.576 | 804.944 |
| AB 16 | 11.722 | 6.377 | 14.893 | 118.863 |
| AB 17 | 11.753 | 1.320 | 18.959 | 271.258 |
| AB 18 | 7.753 | 1.134 | 21.943 | 404.894 |
| AB 19 | 14.487 | 1.115 | 19.643 | 94.568 |
| AB 20* | 11.453 | 3.093 | 23.961 | 94.941 |
| EM 1 | 5.325 | 2.265 | 13.325 | 205.619 |
| EM 2 | 14.010 | 4.243 | 22.010 | 164.506 |
| EM 3 | 5.579 | 4.082 | 13.579 | 136.369 |
| EM 4 | 17.647 | 6.695 | 25.647 | 119.309 |
| EM 5 | 12.930 | 7.603 | 20.930 | 59.014 |
| EM 6 | 13.675 | 8.263 | 21.675 | 205.837 |
| EM 7 | 16.295 | 2.890 | 24.295 | 138.796 |
| EM 8 | 17.847 | 7.687 | 25.847 | 119.793 |
| EM 9 | 16.814 | 2.275 | 24.814 | 118.819 |
| EM10 | 13.593 | 4.253 | 21.593 | 164.448 |
| EM 11 | 17.279 | 4.092 | 25.279 | 138.279 |
| EM 12 | 6.199 | 6.705 | 14.199 | 56.154 |
| EM 13 | 6.199 | 7.613 | 27.899 | 104.634 |
| EM 14 | 19.899 | 8.273 | 31.535 | 93.524 |
| EM 15 | 21.785 | 2.900 | 29.785 | 93.972 |
| EM 16 | 15.485 | 7.697 | 23.485 | 94.126 |
| EM 17 | 10.283 | 2.640 | 18.283 | 105.656 |
| EM 18 | 12.818 | 2.454 | 20.818 | 94.544 |
| EM 19 | 22.835 | 2.435 | 30.835 | 804.285 |

| Sample | Cdeg | HPI | HEI | WQI |
|---|---|---|---|---|
| EM 20* | 21.797 | 4.413 | 29.797 | 119.114 |
| IL 1 | 4.709 | 1.205 | 19.643 | 105.140 |
| IL 2 | 4.011 | 3.183 | 12.011 | 138.161 |
| IL 3 | 1.793 | 3.022 | 9.793 | 118.202 |
| IL 4 | 13.943 | 5.635 | 21.943 | 103.635 |
| IL 5 | 12.143 | 6.543 | 20.143 | 103.774 |
| IL 6 | 14.326 | 7.203 | 22.326 | 83.527 |
| IL 7 | 13.609 | 1.830 | 21.609 | 203.326 |
| IL 8 | 15.041 | 6.627 | 23.041 | 76.590 |
| IL 9 | 16.293 | 1.215 | 24.293 | 103.705 |
| IL 10 | 12.707 | 3.193 | 20.707 | 136.981 |
| IL 11 | 14.526 | 3.032 | 22.526 | 162.922 |
| IL 12 | 10.191 | 5.645 | 18.191 | 83.368 |
| IL 13 | 6.343 | 6.553 | 14.343 | 92.328 |
| IL 14 | 8.945 | 7.213 | 16.945 | 117.946 |
| IL 15 | 5.576 | 1.840 | 13.576 | 103.266 |
| IL 16 | 6.893 | 6.637 | 14.893 | 203.809 |
| IL 17 | 10.959 | 1.580 | 18.959 | 163.412 |
| IL 18 | 13.943 | 1.394 | 21.943 | 70.801 |
| IL 19 | 11.643 | 1.375 | 19.643 | 269.843 |
| IL 20* | 11.643 | 3.353 | 20.024 | 92.702 |
| Average | 12.2788 | 4.180567 | 20.26228 | 180.9707 |

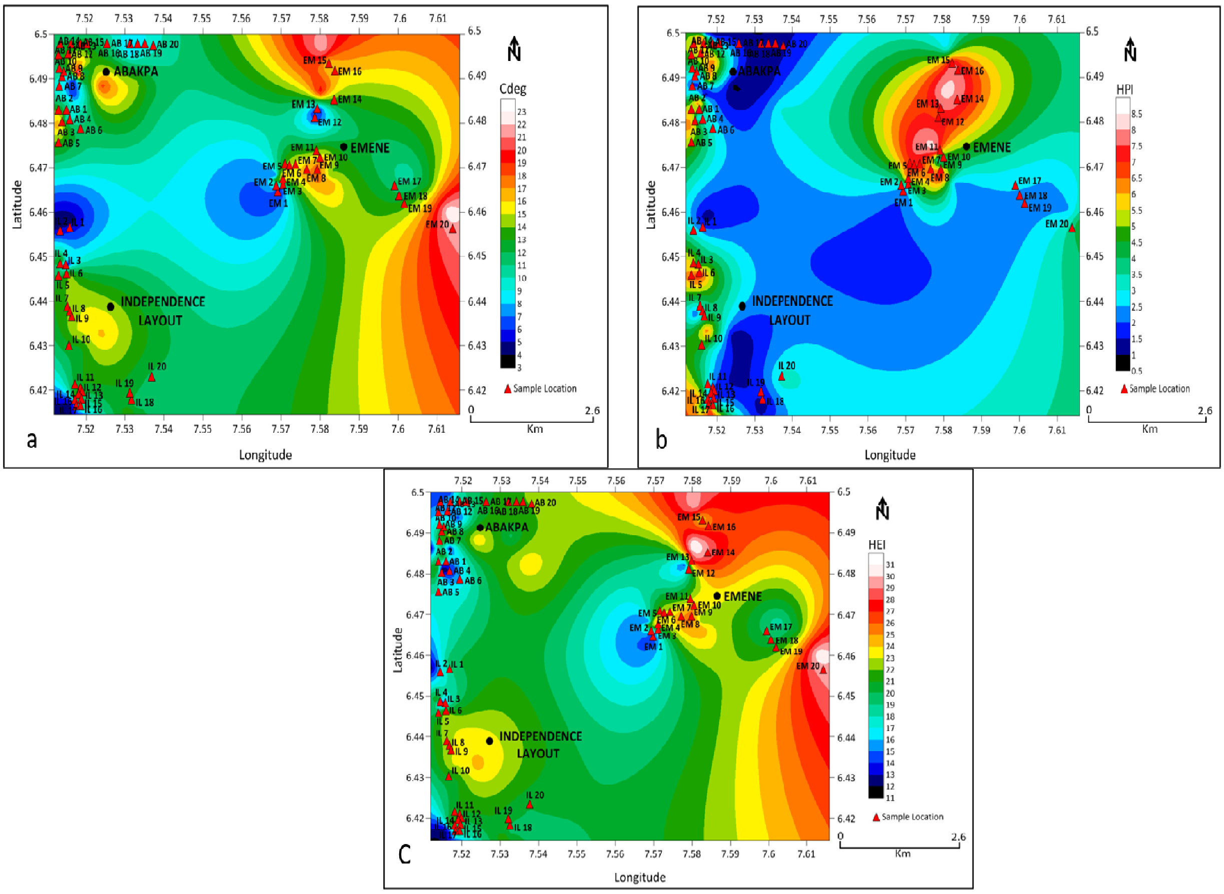


**Fig. 4** Map showing the spatial distribution of (a)$C_{deg}$ ,, (b)HPI, (c)HEI in the study area

 

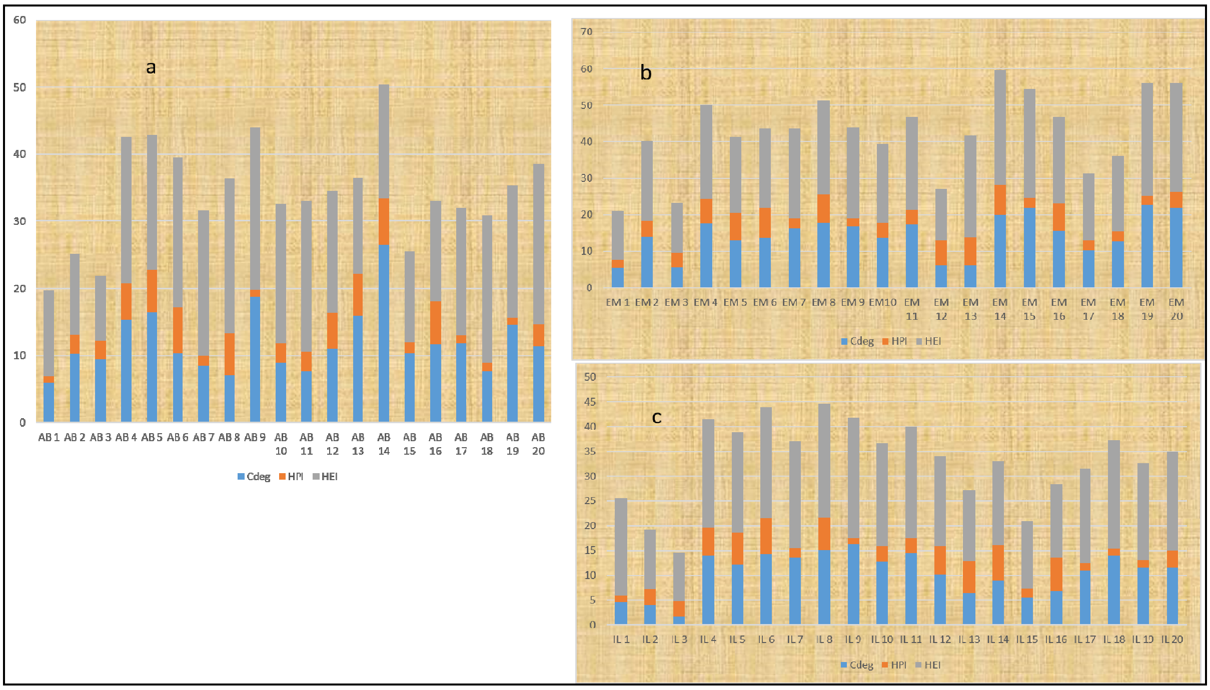


**Fig. 5** Heavy metal pollution plots for the three settlement areas (a = Abakpa, b = Emene, c = Independence Layout)

Groundwater samples within Abakpa have Cdeg values that ranges from 5.965 at location AB 1 to 26.468 at location AB 14 with an average value of 11.95985. Within Emene, Cdeg value ranges from 5.325 to 22.835 at location EM1 and EM respectively with average value of 14.4147, however at Independence Layout, the values are lowest as it ranges from 1.793 at IL 3 to 16.293 at IL 9 with an average value of 10.46185 (Table 2).

### 3.4 Heavy metal pollution index (HPI)

With emphasis on the heavy metal weight scores, the heavy metal pollution index is also summarized in Table 13. When compared with the acceptable ranges, HPI < 10 (low pollution, safe quality), HPI 10–20 (medium pollution, moderately safe quality), and HPI > 20 (high pollution, critical quality) (Edet and Offiong, 2002; Egbueri and Mgbenu, 2020; Egbueri and Unigwe, 2020), generally all the analyzed groundwater samples fall within the low pollution, safe quality (HPI < 10) (see Table 2).

Within Abakpa, the HPI value ranges from 0.945 in location AB1 to 0.955 in location AB 9 with average value of 3.6539, while within Emene, the groundwater shows an average HPI value of 4.9739 and ranges from 2.265 in location EM 1 to 7.697 at EM 16, however the lowest values were also observed within Independence Layout, which shows average HPI of 3.9139 and ranges from 1.205 at IL 1 to 7.213 at IL 14 (Fig 4).

### 3.5 Heavy metal evaluation index (HEI)

HEI was also used to further investigate the heavy metal pollution of ground water in the study area. The computed values where compared with the classified range to ascertain the status of HEI. The classifications according to Edet et al. (2004) are as follow: HEI < 400 (low pollution), HEI 400–800 (medium) Generally all the computed values are within low pollution cluster depicting low pollution (HEI < 400). The groundwater of the area has average HEI values of 18.67775, 23.2815 and 18.8276 for Abakpa, Emene and Independence Layout respectively, with a general average of 20.26228 (Fig.5)

Within the Abakpa area, the HEI values of the groundwater ranges from 9.793 at AB 3 to 23.961 at AB 20, while around Emene, there was a slight increase in the HEI value, ranging from 22.01 at EM 2 to 31.535 at EM 14. Following the same trend for Cdeg and HPI, the HEI value at Independence Layout, has the lowest range from 9.793 at IL 3 to 22.326 IL 6 (medium pollution), and HEI > 800 (high pollution level).

### 3.6 Multivariate Statistical Analysis

Multivariate analysis is crucial approach employed by data scientists in the areas of data distribution and tend investigations, with regards to its quantitative and qualitative outputs. Over the years, it has become a vital tool in data prediction and simulations (Onwuka and Ezugwu, 2019). In this investigation threes approaches were employed namely principal component analysis (PCA), and Cluster analysis, The aim is centered on unraveling the different environment of contaminations, the degree of associated contamination, their direct relationships.

Statgraphic Centurion17 was used to assess the relationships between the possible sources of contamination in the study area, with the analyzed parameters.

**3.7 Principal Component Analysis (PCA).**

The strength of relationships and component weight association between all the analyzed parameters is presented in (Fig. 46). The extracted score stands at ≥ 0.5. PCA is a multivariate technique that is used to identify the most significant parameters from the groundwater and the relationship between them (Danijela, 2015; Onwuka and Ezugwu, 2019; Ezugwu et al., 2019; Mama et al., 2020). Generally in the study area, three components were extracted for all the analyzed parameters (Figs 6 a, b and c).Within the Abakpa area, PC1 contains DO, PAHS, (Table 29), $NO_3$, Na, Phthalate, Cu, Boracol, As, MTBE and total kjeldhal indicating that they are from the same source and can be attributed to timber, domestic and industrial contaminations within Abakpa, based on their parameter associations ( Egbueri et al., 2021; Mama et al., 2021; Ebgueri et al., 2022).

PC2 has high positive score for EC, TDS, BOD, Mn, Zn, Fe, PH, which indicate the heavy metals within this component have higher influence on the groundwater pH, TDS, and BOD. Based on parameter associations, the PC2 can be attributed to solid waste influence (Fig. 6a). PC3 has high component score for Cd, BPA, and Cr which can be attributed to automobile and cosmetic waste influence based on the associated parameters (Onwuka and Ezugwu, 2019). Within the Emene axis, PC1 has high scores for DO, EC, Cd, TDS, PAH, pH, $PO_4$, Boracol, BOD, CPT, $NO_3$, Cu, Pb and MTBE. This component has the controlling effect on groundwater DO, EC, pH, BOD and can be attributed to numerous industrial wastes within Emene and environs (Fig. 6b).

PC2 contains Cr, TOH, phthalate, Fe, BPA, Na, and Mn which can be attributed to automobile waste and timber chemical contamination while PC3 contains Zn and As, which could also be attributed to solid waste contamination based on the associated parameters (Danijela, 2015).Within the Independence Layout and Environs PC1 show high score for DO, As, Pb, Cd, phthalate, BPA, boracol and Na (Fig.6c). This association has the highest effect on the groundwater DO within Emene and Environs (Ezugwu et al., 2019), however within the second component (PC2), high scores where observed for TDS, $NO_3$ , BOD, Cr, CPT, $PO_4$, MTBE, Fe and total kjeldhal which are thought to be associated with domestic, timber and industrial contaminants, and are the major factor controlling the groundwater TDS and BOD (Egbueri et al., 2022).

PC3 has high scores for pH, Mg ,Zn, PAH, Cu and TOC, which can be attributed to automobile and solid waste contaminant within Independence Layout ( Onwuka et al., 2018).

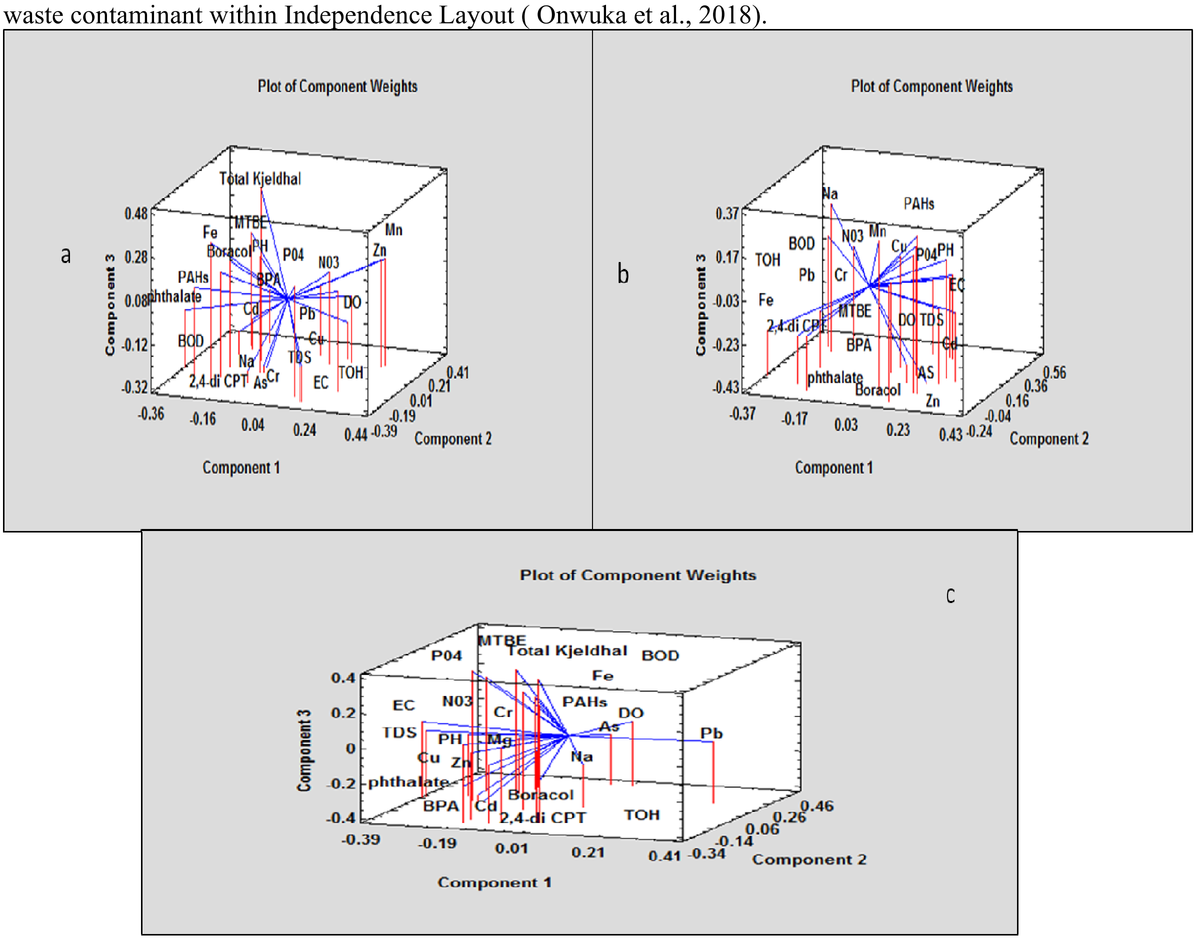


**Fig. 6** (a) Component Weight plot within(a)Abakpa (b) Emene(c) Independence Layout

### 3.8 Results of X-ray Diffraction (XRD) Analysis of Shale Samples

X-ray diffraction is an important technique used in determining the mineral composition of shales. Ten shale samples from the thre settlement area were sampled and subjected to analysis using this method. The result of the analysis shows the presence of 3 minerals that are contained in the shale samples.

The principal mineral (non-clay mineral) contained in the samples is quartz, with different percentage concentrations in the analyzed samples. Other minerals present include berlinite and strengite. Amongst these, some occur as oxides while others as phosphates and phyllosilicates. Quartz make up the framework grains while berlinite, which is isostructural with quartz, could occur as cement after being broken down to clay minerals during weathering. Strengite constitute the accessory mineral although it could also act as a cement.

The results of XRD shown in Table 3 indicates variations in the mineral composition across the locations. Quartz, a detrital mineral is the most dominant mineral present; with its highest concentrations (100%) at Abakpa (AB SH 4). Strengite (9-40%) concentrations are relatively low especially in shales samples colleectd in Abakpa and Independence Layout. In Emene, the percentage of Strengite ranges from 13.00 to 40 %. The occurrence of quartz was not observed in one sample (EM SH 1), however, they it consists of strengite (40%) and berlinite (60%) respectively. Berlinite was detected mainly in shales samples collected in Emene and Independence Layout, with contration values that vary between 26% in IL SH 1 and 60% in EM SH 1 (Table 3). Only AB SH 2 (42.13 %) showed the presence of berlinite in Abakpa. The graph showing the detected mineral spectrums in the analyzed shales are shown in Figs 7-9 below.

**Table 3** Results of x-ray diffraction (XRD) analysis of shale samples showing mineral percentages

| Mineral Composition | AB SH 1 (%) | AB SH 2 (%) | AB SH 3 (%) | AB SH 4 (%) | EM SH 1 (%) | EM SH 2 (%) | EM SH 3 (%) | IL SH 1 (%) | IL SH 2 (%) | IL SH 3 (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 73.26 | 57.87 | 70.11 | 100.00 | - | 26.00 | 82.20 | 65.00 | 61.00 | 82.50 |
| Berlinite | - | 42.13 | - | - | 60.00 | 45.32 | - | 26.00 | 39.00 | - |
| Strengite | 26.74 | - | 29.89 | - | 40.00 | 28.68 | 13.80 | 9.00 | - | 17.50 |

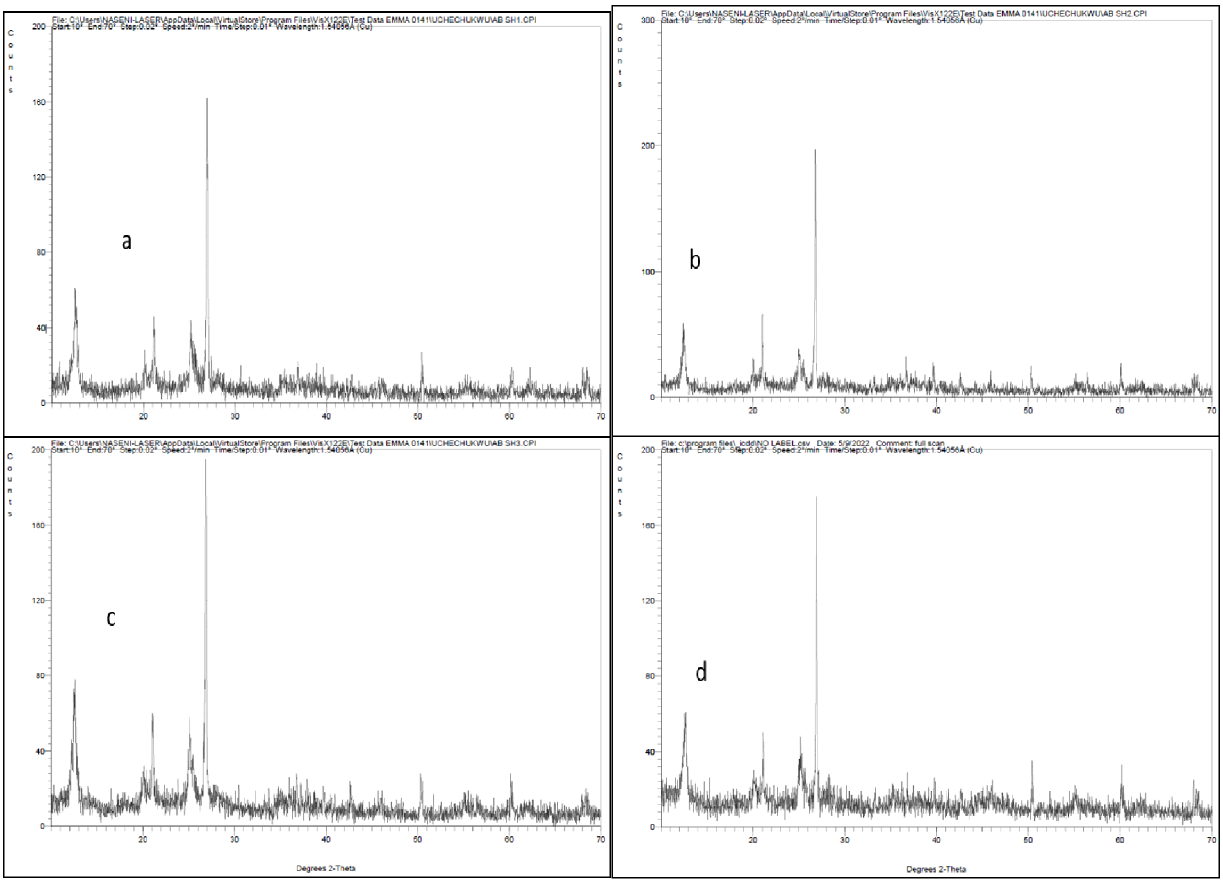


**Fig. 7** X-ray diffraction graph showing mineral composition in ABK SH 1-SH4

 

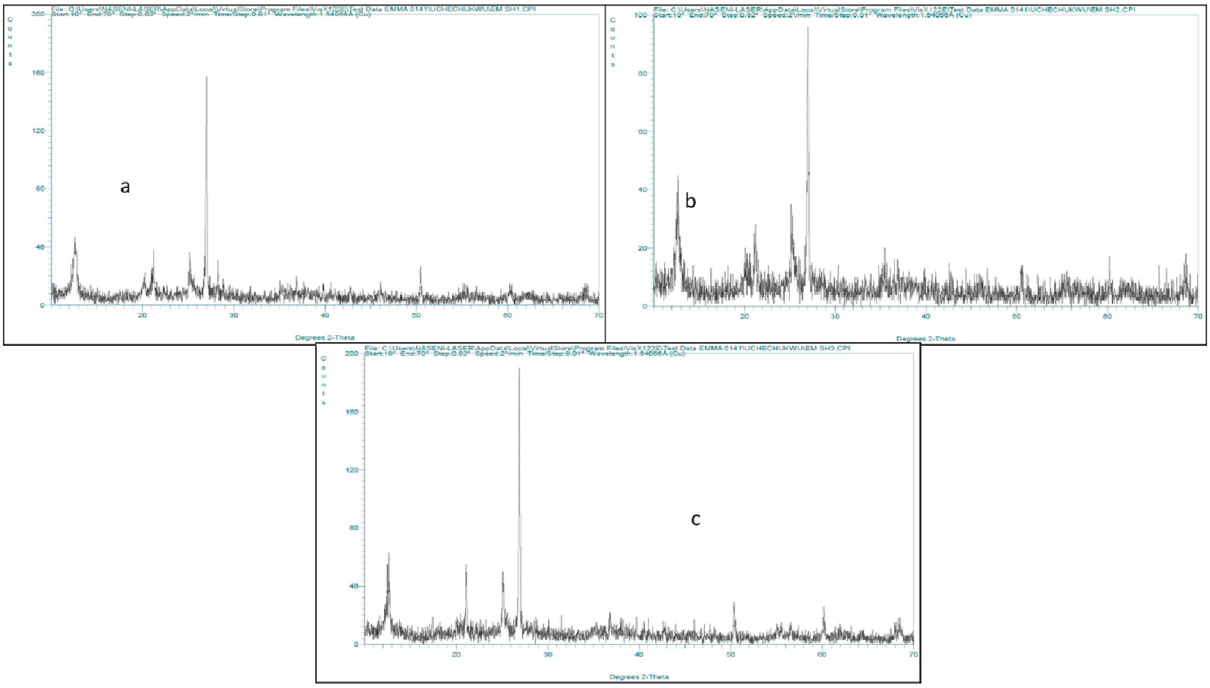


**Fig. 8** X-ray diffraction graph showing mineral composition in EM SH 1-SH3

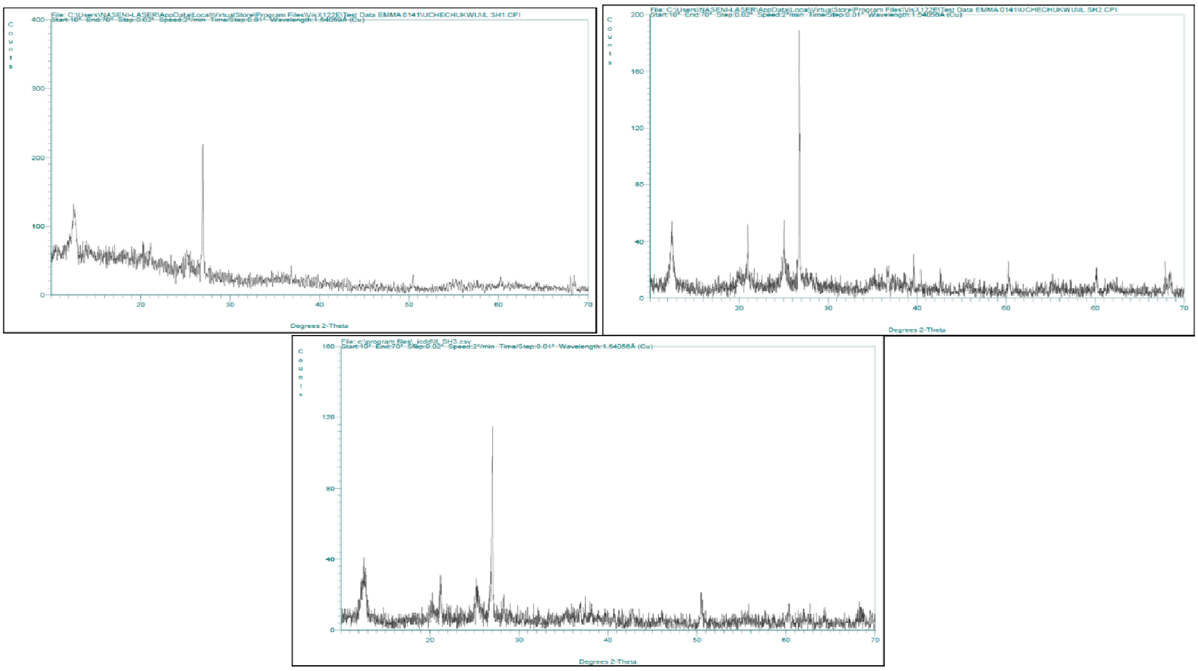

**Fig. 9** X-ray diffraction graph showing mineral composition in IL SH 1-SH3

The combined effect of burial, compaction and chemical reaction between rock and fluid are collectively known as diagenesis. These processes could result in chemical by-products that are capable of affecting groundwater quality.

At the time of deposition, sand-size grains (quartz and berlinite) created a self-supporting framework. Finer particles such as strengite formed the detrital matrix and the remaining volume was pore space. Berlinite, an alluminium phosphate having similar crystal structure as quartz, could have been formed under a specific range of temperature, pressure and oxidation state unique to it during burial. Strengite (iron phosphate) could have formed as an altertaion product of a primary phosphate mineral (such as triphylite). Strengite occurred because the oxidation conditions were high enough to oxidize the iron of the primary phosphate mineral from a ferrous (+2) state to the ferric (+3) state as is needed for strengite (Boyd, 2020). The presence of strengite is therefore an indicator of high oxidation of the shale host rock. This is reflected in the high DO values obtained in the analyzed water samples. The occurrence of strengite in the host rock, however, did not result in elevated values of iron and phosphate in groundwater samples collected from the three settlement area. Therefore, the influence of geogenic factors in groundwater contamination within the study area is very minimal.

### 3.9 Water Quality Index (WQI)

The water quality index was employed to assess the suitability of the groundwater within the study area for consumption by integrating the individual and collective effect of all the physicochemical and organic parameters**.** This technique has been elaborately used by groundwater researches such as Olasehinde et al. (2015), Onwuka et al. (2018), Mama et al. (2020, 2021), Cumar and Nagaraja (2011), Edet and Offiong (2002), Ezugwu et al. (2019) and Egbueri (2020). WQI< 50 (Excellent) WQI 50-100 (Good water), WQI 100-200 (Poor water) WQI 200-300 (Very poor water) and WQI >300 (Unsuitable for drinking). None of the computed WQI fell within the excellent water quality within the study (Fig. 10). Generally 28.3% of the groundwater fell under the good water quality, 41.6% within the poor water quality, 20% within the very poor water quality and 10% within the unsuitable water condition Table 4. Fig. 10, which shows the spatial distribution of WQI values within the study area, shows that most of the water samples deemed very poor in quality or unsuitable for drinking are located within the Abakpa and Emene settlement areas.

**Table 4** Water quality index percentage trend

| WQI | % | Location | Inference |
|---|---|---|---|
| <50 | 0 | None | Excellent |
| 50-100 | 28.4 | AB 8,AB 9, AB 11, AB 19, AB 20, EM 5, EM 12, EM 14, EM 15, EM 16, EM 18, IL 6, IL 8, IL 12, IL 13, IL 18, IL20 | Good water |
| 100-200 | 41.6 | AB 12, AB 13, AB 16, EM 2, EM 3, EM 4, EM 7, EM 8, EM 9, EM 10, EM 11, EM 13, EM 17, EM 20, IL 1, IL 2, IL 3, IL 4, IL 5, IL 9, IL 10, IL 11, IL 14, IL 15, IL 17 | Poor water |
| 200-300 | 20 | AB 2, AB 4, AB 5, AB 6, AB 10, AB 14, AB 17, EM 1, EM 6, IL 7, IL 16, IL 19 | Very poor water |
| >300 | 10 | AB 1, AB 3, AB 7, AB 15, AB 18, EM 19, | Unsuitable |

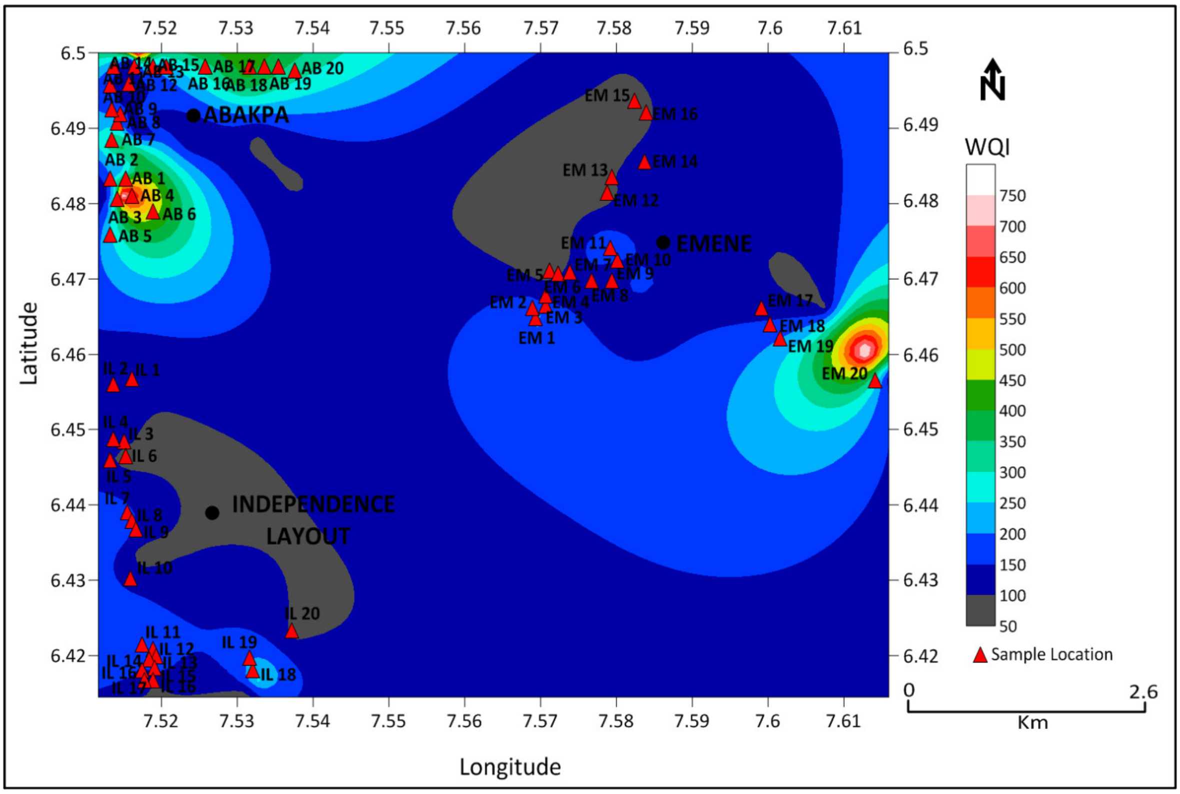


**Fig. 10** Water quality index spatial distribution map of the study area

### 4.0 SUMMARY

This study has shown that the groundwater quality within the study area is under serious pollution threats from dumpsite leachates, heavy metals and organic contaminants, which is the result of increase in the rate of urbanization within in the study. This portends severe health risk for the water users, most of whom consume groundwater without any form of treatment, which calls for appropriate measures to protect and remedy polluted groundwater for safety purposes.

Inventory of Dumpsites were done and categorized into domestic, industrial, commercial and hazardous wastes, however multivariate statistical analysis extracted three anthropogenic diagnostic factors controlling the chemistry based on the parameter associations

The heavy metal pollution indices (Cdeg, HPI and HEI) indicated a low level of heavy metal contamination of groundwater in the areas.

From the WQI analysis, 28.3% of the groundwater fell under the good water quality, 41.6% within the poor water quality, 20% within the very poor water quality and 10% within the unsuitable water condition.

**4.1 Remediation Measures and Groundwater Management**

- . ESWAMA (Enugu State Waste Management Authority) and other relevant agencies within the state should construct three (3) mega sanitary landfill within Emene, Abakpa, and Independence Layout. This landfill will serve as a central and final disposal and incineration point. Indiscriminate waste disposal should be discouraged by the government by enacting appropriate laws against such act. Companies within Emene should be prohibited from open disposal of their untreated effluents on the open soil surface, which can percolate and contaminate the groundwater. Effluent treatment should be encouraged to the companies by the government, in other to openly dispose less toxic wastes into the environment.
- Periodic groundwater status monitoring should be encouraged by ESWAMA and other relevant agencies, as to have a regular established audit mostly within the Industrial layout, which has the tendency of increased pollutants reaching the groundwater. This can be done, by having pilot holes within the area to monitor mostly point source contaminants.
- Public enlightenment should be done periodically on the danger, environmental impact, and their associated implications of indiscriminate human, domestic, and industrial waste disposal by the Enugu state ministry of environment. Such health education is very vital because, without attitudinal change, the groundwater within the study area will continue to be vulnerable to contaminants.
- With regards to some already contaminated groundwater within the study area, and owing to the fact most boreholes and hand-dug wells are individually owned, in-situ water treatment is unlikely possible, owing to the cost implications, however, pump and treat ex-situ treatment method is greatly recommended to improve the groundwater quality within the area. Some of the ex-situ treatment options include Filtration (for physical parameters), ion exchange, oxidation, carbon absorption, and chemical precipitation.
- The Enugu state ministry of water resources should supervise and give approval of sites far away from pollution source centers. This is because the indiscriminate siting of water sources without considering its nearness to pollution sources has predisposed the water sources to undue contamination.

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