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# Geospatial Analysis of Heavy Metal Intrusion in Groundwater Resources of Isoko North Local Government Area, Delta State, Nigeria: A GIS and AHP Approach

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**Abstract**

This study compared the regional variations of heavy metal intrusion in subterranean water resources of Isoko North Local Government Area, Delta State, using ten (10) spatially distributed boreholes. The data were subjected to the Heavy Metal Index (HMI) technique to determine the significant contamination rate (with the World Health Organization Standard and the Nigerian Standard for Drinking Water Quality as the control variables). The investigation revealed that lead (Ppm) values ranged from 0.11 to 0.18, with higher concentrations in Owhelogho (0.18), Iyede (0.18), and Ellu (0.17). The Iron (Ppm) value ranges from 0.31 to 0.43, with all locations having significant values slightly higher than the WHO and NSDWQ norm of 0.3. The heavy metal index test yielded a class "II" grade, suggesting the presence of lead and iron oxide in trace amounts. The groundwater potentials and vulnerability assessment level results were validated using the AHP Pairwise analysis program. Rainfall, height, slope, drainage density, lineament density, land use land cover (LULC), and geology are among the components evaluated. It is significant to highlight that rainfall, accounting for 25.88%, and geology, accounting for 23.79%, are the two primary influencing elements in heavy metal contamination of groundwater in the area. The area's vulnerability model, created using a GIS-based weighted overlay, shows 75.5% of the area to be highly vulnerable, 17.22% moderately vulnerable, and 7.29% lowly vulnerable.

***Keywords***: *Boreholes, geospatial, groundwater, heavy metals, intrusion, rocks.*

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## 1. Introduction

Water is a vital necessity for life and wellness (Abubakar, 2018). Over the last two decades, the globe has made some progress in improving access to safe drinking water (IDW) and hygiene in accordance with the Sustainable Development Goals (SDGs) (WHO 2017 and Owamah, 2020). While Sub-Saharan Africa had a population of 319 million people in 2015, only 24% had access to improved drinking water (IDW). Latin America and the Caribbean, West Asia and North Africa, East Asia and Southeast Asia had 65%, 90%, and 94%, respectively (Abubakar, 2018). It is also worth noting that the Sub-Saharan region is home to 70% of the world's population that depends on surface water for drinking (UNICEF/WHO, 2015 p. 11). Between 1990 and 2015, 723 million new piped water customers were registered in Eastern Asia, while Sub-Saharan Africa had a decrease from 43% to 33% (UNICEF/WHO, 2015 p. 9). In 2015, 67% of Nigeria's population was reported to have access to improved drinking water. However, this fell short of the 77% MDG objective and significantly below than the global average of 91% (UNICEF/WHO, 2015 p. 11). According to the 2013 Nigeria Demographic and Health Surveys, 50.8% (rural) and 14.4% (urban) of Nigerian households relied on unimproved drinking water sources (Abubakar, 2019 and Owamah, 2020). According to Plummer et al., (2020) groundwater is the most reliable source of water supply for both human and industrial use. Nevertheless, owing to ecological and societal considerations, the use of this precious resource has become problematic in most parts of the world (Vasanthavigar et al., 2012; Li et al., 2016 and Egbueri, 2020). The global water demands are met by surface freshwater reservoirs and underground groundwater (Egbueri, 2020). Groundwater has been described by (Plummer et al., 2020; Li et al., 2020; Pinsri et al. 2022; Xu et al., 2023 and Zhu et al., 2023) as water that exists directly beneath the earth's surface, filling fissures and broken open spaces in all types of rock, as well as the pore spaces between porous grains in sediment and clastic sedimentary rocks. Nonetheless, groundwater is more broadly dispersed, helpful, and relatively pure than most polluted surface waters (Agunwamba, 2000), but the threat to it is mounting due to population development and increasing demands (Egbueri et al., 2019; Sadeghi, 2020; and Shams et al., 2020). Groundwater is used for residential, industrial, and other purposes by around one-third of the world's population (Vasanthavigar et al., 2012; Singh et al., 2017; and Adeyemi & Ojekunle, 2021). Rising residential, industrial, and agricultural demand has put further strain on this resource, particularly in developing nations with fragmented water infrastructure (Egbueri et al., 2019; Long et al., 2020; Pinsri et al., 2022; and Shajedul and Mustafa, 2023). Natural as well as human-made variables may contribute to the degradation of this resource (Kumar et al., 2022). This degradation is largely caused by natural forces that are inherent in the geological conditions (Odukoya, 2015 and Ravindra and Mor, 2019). When the chemical composition of groundwater differs from the World Health Organization's (WHO) recommended drinking water recommendations due to anthropogenic and natural pollutants, the groundwater is deemed unfit for usage (WHO, 2017), which portents the need for monitoring heavy metal ions through advanced sensing technique as described by Egbosiuba et al. (2024), Patent No. NG/PT/NC/O/2024/16574. Iron, arsenic, nitrate, manganese, fluoride, and boron are among the common heavy metals and radionuclides that are anthropogenic sources of grand water contaminants (WHO, 2017 and Bodrud-Doza, 2019). The area's aquifer is located in the bottom soil layers and is filled with water underground; the water table, which is the highest point of this layer, is a highly reliable source of most well waters (Buddermeier and Schloss, 2000). Shallow and mostly polluted aquifers produce an estimated 700m3 of subterranean water (Cunningham and Cunningham 2006), and the majority of the boreholes drilled in the study area are found to have been drilled into these shallow aquifers, which causes them to interact with the rocks in the layer. Undoubtedly, insufficient public drinking water systems in many Nigerian cities and towns have fueled the expansion of privately operated borehole and open well systems (Anomohanran, 2014). These boreholes are allegedly drilled by untrained craftsmen who are ignorant of the hydraulics and hydrogeology of the region they are working in. As a result, no geophysical survey was carried out in the region to obtain geological data prior to drilling. Therefore, as soon as water is found, drilling is stopped. This study, which aims to raise awareness of the dangers associated with drinking tainted groundwater, is based on this knowledge. The investigation's design and technique flow diagram is shown in figure 1, and other data sources are listed in table 1 for a meaningful study.

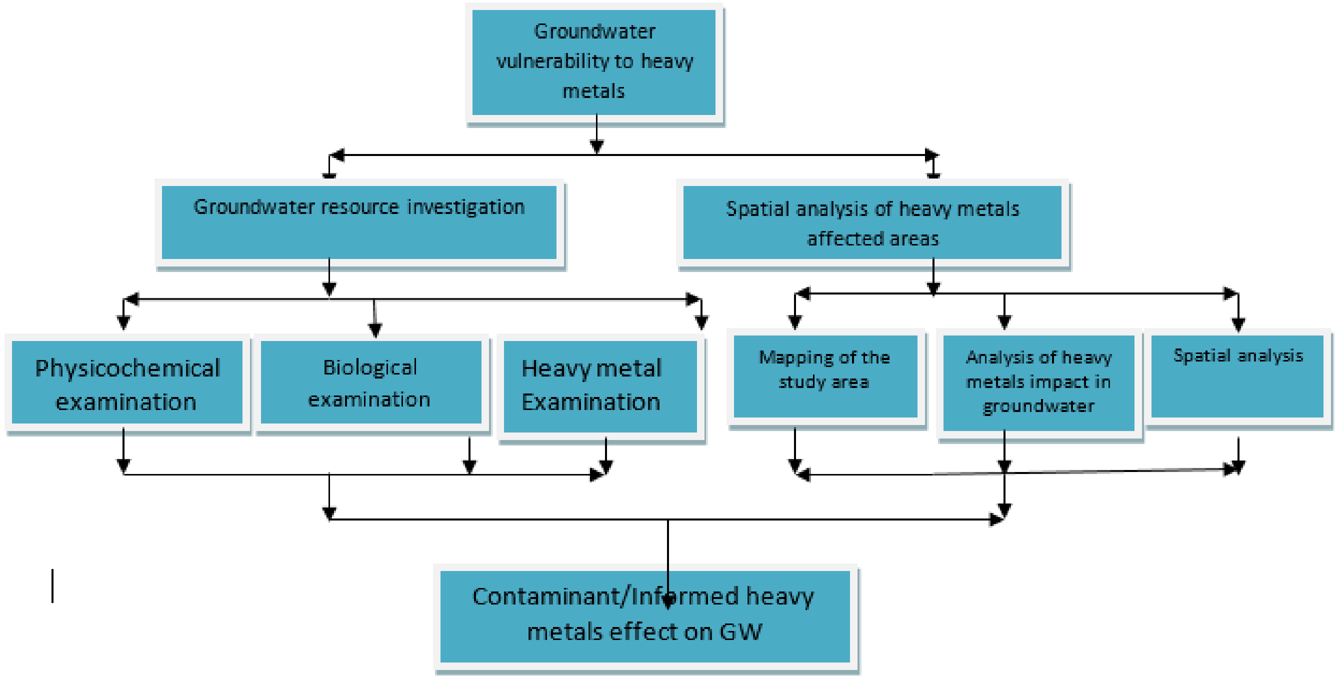


***Figure 1:*** *Shows the investigation's design and technique flow diagram*

## 2. Materials and Methods

**Study area:** The region being studied spans approximately 479.0 km2, from Latitude 50 151 N to Latitude 50 401 N of the equator to Longitude 60 151 E to Longitude 60 251 East of the Greenwich Meridian. (Olomo & Ejemeyovwi, 2008), as illustrated in figure 2.

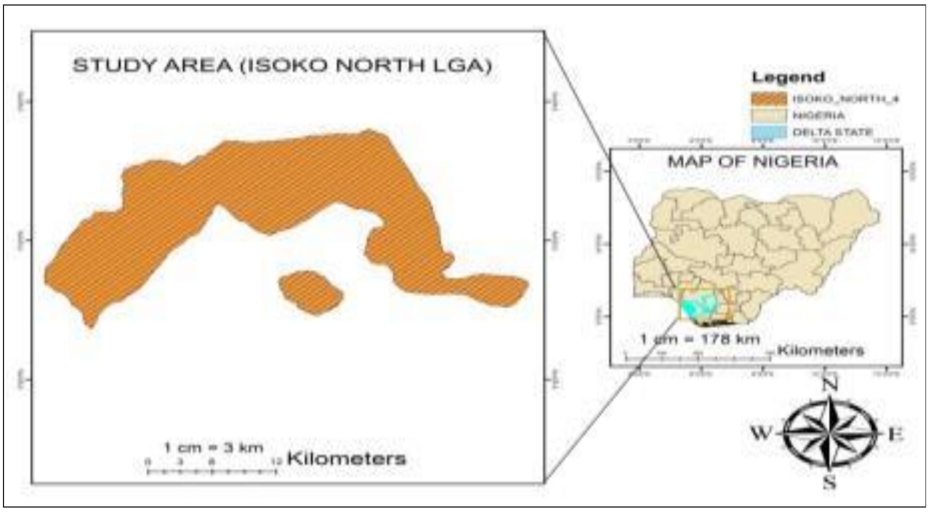


***Figure 2:*** *The study area, a Sub-Saharan country in West Africa, is depicted on the map*

The region enjoys hot, humid weather typical of a tropical climate, as well as distinct rainy and dry seasons. The rainy season lasts from April to October, with the exception of August, when there is a brief period of sunny, dry weather. Temperatures range from 280°C to 330°C, and annual rainfall ranges from 2500mm to 3000mm (Olomo & Ejemeyovwi, 2008). The region's geological past is thought to have been founded on clastic sediments and alluvium deposits from the Benin Formation (Nwajide, 2013 and Plummer et al., 2020). A few mudrocks, siltstones, and ironstones can be found in the Asaba region. However, the majority of the Benin Formation in the studied region is composed of sand-stones (Nwajide, 2013). Grain size distribution, hydraulic conductivity, transmissivity, and pump test estimates are among the features of prolific aquifer systems found in Benin's sediments and soils, according to previous reports on the country's geologic formation (NSDQW 2007; Nwajide, 2013 and Egbueri et al., 2019) and (Anomohanran, 2014), which have examined further studies regarding the region's geologic past. According to (Aweto and Akpoborie, 2011), among many other things, it has the features of a flat, featureless plain that slopes seaward and is mostly composed of sandstone formation. Delta State's interconnected subterranean waterways are included in this description. The geological formation of the area is characterized by a level, gradually sloping, and uninspiring plain that is primarily composed of sandstone. When rainfall reacts with the underlying elements of rocks to extract chemicals or other compounds, heavy metals are produced (Anomohanran, 2014).

***Description of SDGs on water management***

One of the main goals of urban development is to manage and potentially contain recurring groundwater contamination. This goal is even included in the United Nations' global sustainable development agenda (UN, 2015: SDGs), which includes the following goals: sustainable cities and communities (SDG-11), clean water and sanitation (SDG-6), and good health and wellbeing (SDG-3). Ensuring the environment is secure from air, water, and land threats and advancing the research that supports the sustainability of ecosystem processes are the main goals. Drought, floods, and disasters related to water (SDG 11.5) are examples of natural hazards that can significantly affect the attainment of SDG-6, which is to guarantee the availability and sustainable management of water and sanitation for everyone, while SDG-3 placed emphasis on ensuring everyone lives healthily and is happy. Sustainability science must further its agenda on investigating the temporal and spatial aspects of heavy metal contamination, as well as its effects on local ecosystems and the efforts being made to identify contaminants' hazards on groundwater resources and to address them appropriately, given the new global realities surrounding land and water pollution. The current study is important for achieving SDGs for both the study area and the region as a whole since it conducts a regional analysis of heavy metal contamination with a comprehensive assessment of its influence on groundwater resources in Isoko North LGA.

***Post-processing and data preparation***

Data pertaining to rainfall, digital soil data, drainage density, geomorphology, SRTM, lithology, groundwater susceptibility, elevation/slope, rainfall, and local sources of heavy metal pollution of the local groundwater were the primary data sets that required preparation (table 1).

We used the following steps for a meaningful, result-oriented approach to accomplish these established goals, which included creating a contour map to verify the elevation/slope data. Using ESRI ArcGIS's data management capabilities, the rainfall and land use data that represented the study area of interest were carefully cropped from their base maps.

***Table 1:*** *The sources and needs for research data*

| S/no. | Data Type | Formats | Sources |
|---|---|---|---|
| 1 | Flood Site | GPS coordinates and images | Filed works |
| 2 | Study region's political boundary | Shapefile (Vector) | Accessed GIS data from MAPOG online at https://gisdata.mapog.com/nigeria. |
| 3 | Topographic characteristics of the research region | Shapefiles (Vector) | Digitally derived from Google Earth |
| 4 | Bore-holes | 10 (4") Existing bore-holes (for water samples) | Field-work |
| 5 | Summaries on literatures | Quantitative analysis | Scientific data-bases |
| 6 | Land-use | Geotiff (Raster image) | Sentinel-2 10 m land use/coverage data from ESRI hub is available at https://livingatlas.arcgis.com/landcover/. |
| 7 | Soil data in digital format | Shape files | HWSD (globally standardized soil database) Version 1.2 at 900 m resolution and the Geologic map of Nigeria |
| 8 | Data from Digital Elevation Model | Geotiff (Raster image) | NASA's USGS earth explorer *https://earthexplorer.usgs.gov/* |
| 9 | Digital rainfall data | Geotiff (Raster image) | PERSIANN-Cloud Classification System (PERSIANN-CCS). **FTP also available:** *ftp://persiann.eng.uci.edu/CHRSdata/PERSIANN-CCS* |

***Geo-Data and Vulnerability Map Production***

Computer-based systems called GIS and AHP were used to handle, store, alter, analyze, and display geographic data in order to tackle a number of challenging environmental issues. Therefore, the weights of eight influencing factors—rainfall, geology, geomorphology, lineament density, drainage density, elevation, slope, and LULC—are superimposed in the ArcGIS platform under the spatial analysis tool to define the groundwater potential zone. Based on their contribution to groundwater recharge, all of those influencing factors were chosen. In ArcGIS 10.8, the topographical map and the Isoko Region imagery were geo-referenced to the world coordinate system (WGS 84). While the drainage network and villages were modeled from the topographical map, the study area's land use map was obtained from Sentinel-2 10 m land use/coverage data from ESRI. The geologic map of Nigeria was also georeferenced with the soil texture map of Isoko North LGA and its surroundings. Criteria for Vulnerability: The vulnerability criteria included in K.D. Geopel's Analytical Hierarchy Process (AHP), version 15.09 (2018), were ranked in this study using these techniques. The Analytical Hierarchy Process (AHP) is a multi-criteria basic leadership method that provides a systematic approach to assess and integrate the effects of various variables, including a few aspects of dependent or autonomous, subjective as well as quantitative data (Berezi et al., 2019 and Zewdie et al. 2024). In order to assign a ratio value to each criterion map, the ranking approach was chosen because the criterion weights are often established during the consultation process with choice or decision-makers (Tafese, 2022 and Nkunonwo, *et al*. 2024). Every statistic taken into account in a positioning strategy is positioned according to the leader's inclination. To generate rule values for every assessment unit, the essentiality of each factor that contributed to the iron oxide infiltration was examined (see table 1 for a list of datasets and procedures used in achieve these aims and figures 3 – 11 below for geo-spatial maps produced from the exercise). ArcGIS 10.8 was used to classify a vulnerability level in the location and determine the spatial extent of each vulnerability level. The individual patches can then be classified based on texture, geometric properties, dynamic evolution, and cloud top height. These classifications aid in assigning rainfall values to pixels within each cloud based on a specific curve describing the relationship between rain-rate and brightness temperature (Nguyen et al. 2019).

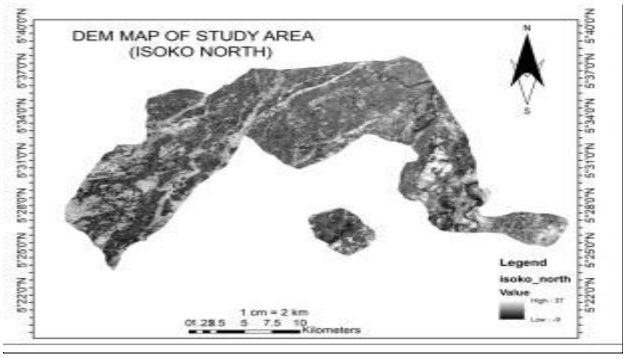


**Figure 3:** Isoko North LGA's SRTM data, which was produced using the USGS 30-m horizontal resolution SRTM.

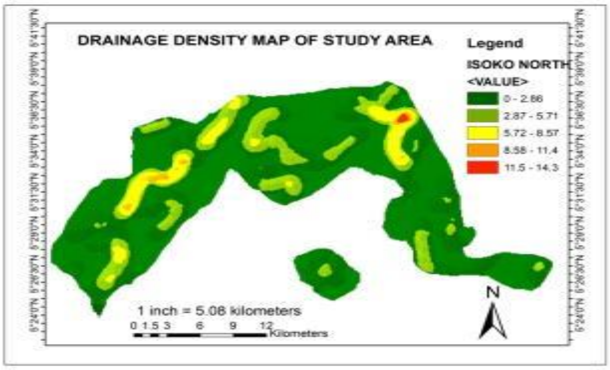


***Figure 4:*** *Isoko North LGA drainage density derived from the USGS 30-m horizontal resolution SRTM.*

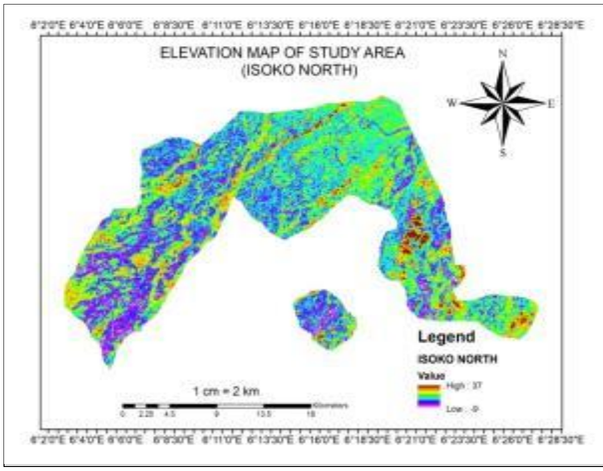


***Figure 5:*** *Elevation map of Isoko North LGA displaying the Somreiro-Warri Deltaic plains, lagoonal marshes, and back fresh water*

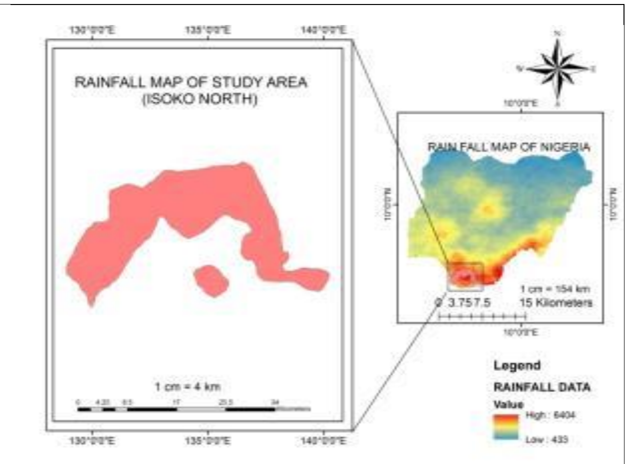


***Figure 6:*** *Displays two units of high and low rainfall areas based on Isoko North's rainfall map data*

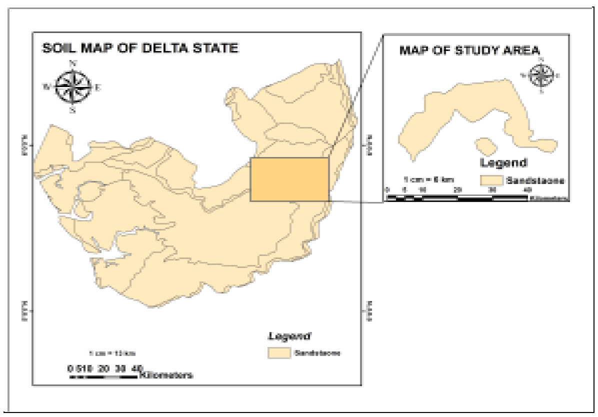


***Figure 7:*** *Isoko North LGA soil map data displaying a uniform sandstone unit*

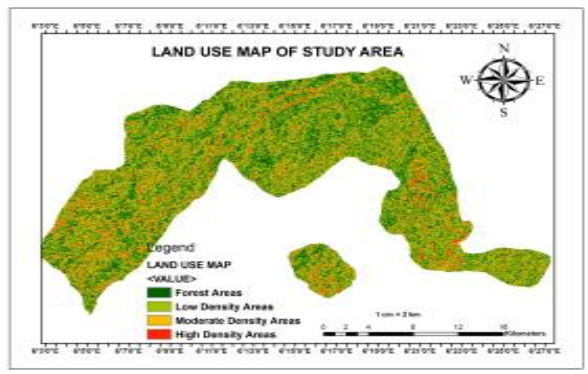


***Figure 8:*** *Isoko North LGA's LULC data displaying low- to high-density areas*

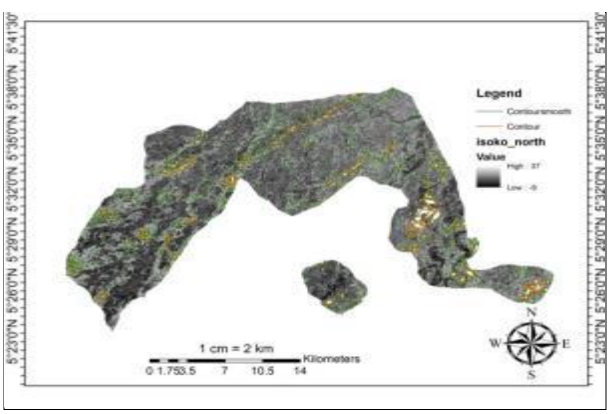


***Figure 9:*** *Isoko North LGA contour map produced using the USGS 30-m horizontal resolution SRTM.*

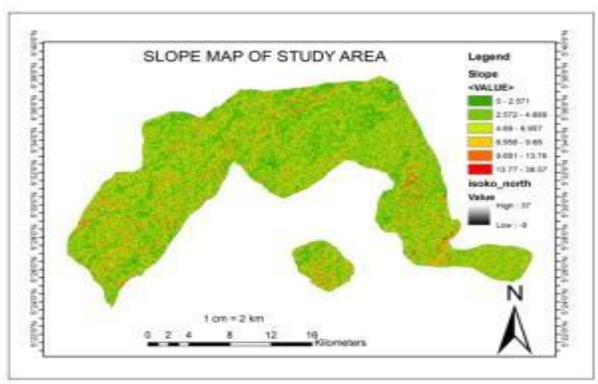


***Figure 10:*** *Isoko North LGA slope map produced using the USGS 30-m horizontal resolution SRTM.*

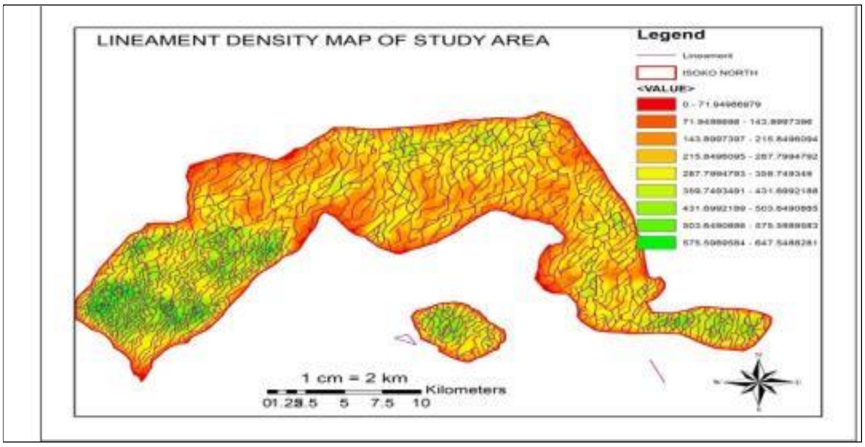


***Figure 11:*** *The USGS 30-m horizontal resolution SRTM's produced lineament density map of Isoko North LGA*

***Groundwater vulnerability and weighted overlay***

Naturally, the creation of a groundwater quality vulnerability map for the study area is the most important outcome of the geospatial analysis conducted for this study. The weighted overlay technique in the GIS spatial analyst tool was used to combine different produced datasets in order to accomplish this. We combined eight data sets that represented important attribution and causative factors of groundwater vulnerability to contaminated water, assigning weights based on the evidence from earlier research, such as Zewdie et al. (2024) and Nkunonwo et al. (2024), and the variable's varied acknowledged importance. The assumed weights and overlay variables are displayed in Table 2. Three categories of groundwater vulnerability were identified: low, medium, and high. In order to establish a connection between these profiles and the land use and land cover features of the region, estimations of the spatial extent for each vulnerability profile were evaluated in relation to the local community.

***Table 2:*** *Overlay variables and the assumed weights*

| S/no | Variable | Classes | | Weight(%) |
|---|---|---|---|---|
| **1** | Rainfall | High | 6404 | 26 |
| | | Low | 433 | |
| **2** | Geology | Sedimentary terrain | | 24 |
| **3** | Lineament Density | Very low | 1 | 13 |
| | | Low | 2 | |
| | | Medium | 3 | |
| | | High | 4 | |
| | | Very High | 5 | |
| **4** | Drainage Density | Very low | 1 | 9 |
| | | Low | 2 | |
| | | Medium | 3 | |
| | | High | 4 | |
| | | Very High | 5 | |
| **5** | Elevation | Very High | 1 | 5 |
| | | High | 2 | |
| | | Medium | 3 | |
| | | Low | 4 | |
| | | Very Low | 5 | |
| **6** | Slope | Very low | 5 | 7 |
| | | Low | 4 | |
| | | Medium | 3 | |
| | | High | 2 | |
| | | Very high | 1 | |
| **7** | LULC | Water body | 1 | 7 |
| | | Forested | 3 | |
| | | Low density | 1 | |
| | | Medium density | 3 | |
| | | High density | 5 | |
| **8.** | Geomorphology | Homogenous SST | | 9 |
| | | | | 100 |

Three categories of groundwater vulnerability were identified: low, medium, and high. Each vulnerability profile's estimated spatial extent was evaluated within each area in order to connect these profiles to the land use and land cover features of the region (Table 3).

***Evaluation of groundwater properties and quality***

Ten existing boreholes, each ranging in diameter from 4 to 6 inches and with an average depth of 40 meters in the basement rock, serve as sampling stations for groundwater quality analysis. The authors made certain that the boreholes they chose were easily accessible, shallow, constantly used, and located well within the floodwater-infected area, even though they were also chosen at random using the GIS (see table 4 for sample coordinated locations).

***Table 3:*** *Spatial Features of the Isoko North LGA Groundwater Vulnerability Model*

| Vulnerability Profile | Estimated Spatial Extent (Km$^2$) | % Coverage | Enclosed Communities |
|---|---|---|---|
| **Low** | 34.9 | 7.29 | Ozoro |
| **Medium** | 82.5 | 17.22 | Ofagbe |
| **High** | 361.6 | 75.5 | Emevor |

To maintain their natural qualities, the water samples from the boreholes were kept in 2-liter plastic bottles with clear labels and then kept at 4°C for further examination. The water samples from each borehole were tested for bacteriological, chemical, and physical characteristics as well as the presence of heavy metals. The tests were conducted at the Chemical Engineering Laboratories of the Delta State University of Science and Technology, Ozoro, Nigeria. The selection of what is being examined in this study for each of the factors is mostly influenced by the designs of other research, for instance Amal et al. (2020). This comprises Cu, Zn, K, Mg, Na, Pb, Ca, Mn, Cr, and Hg in addition to total iron (Fe). The atomic absorption spectrophotometer (AAS) was used to measure the concentrations of the following heavy metals: Ca2+, Mg2+, Na+, K+, Fe2+, Cu2+, Zn2+, and Pb2+. The values of the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO) served as control variables. Samples were analyzed to the fullest degree possible, shortly after collection, for pollution parameters to avoid deterioration owing to environmental causes using prescribed analytic procedures (WHO, 2017 & NSDWQ, 2007). Table 5 displays the results of the water sample analysis and parameter comparison conducted in cooperation with the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO).

## 3. Results and Discussion

The analysis's findings, which are displayed in Table 6, indicated that iron and lead were highly prevalent. The flow chart in figure 1 provides a visual representation of the techniques used (see figure 12). Ten water samples, all located within the study area, were taken into consideration for this investigation (see figure 13). In all directions of the study location, groundwater flows in high yield, according to a geospatial analysis of the DEM of the study area that delineates relief, groundwater flow direction, and hydraulic gradient of the location, including groundwater vulnerability assessment. This raises health concerns because the water is also consumed by dozens of the location's residents. The impact of heavy metal contamination on groundwater resources in key areas of Isoko North LGA has been studied, along with key parameters and empirical findings. This study discusses the implications of the findings for stakeholders and how they should guide constructive action to mitigate the impact on groundwater resources and, of course, on social, biological, and environmental systems.

***Groundwater susceptibility to the intrusion of heavy metals***

A considerable number of geographic features in the study area are at risk of heavy metal contamination of groundwater resources, as determined by evaluating the spatial extents of the high- and medium-vulnerability areas in the groundwater map of figure 12.

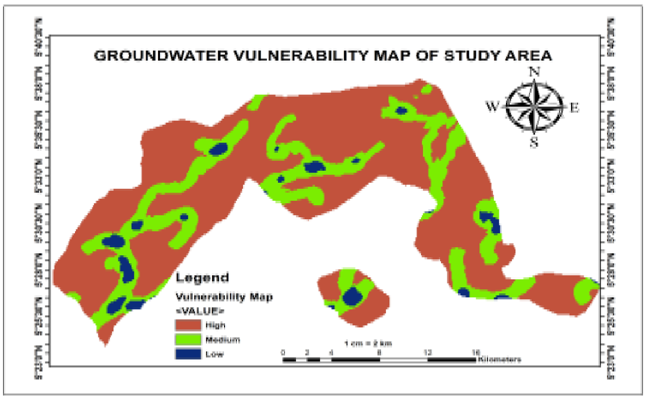


***Figure 12:*** *Three levels of sensitivity are depicted on the groundwater quality vulnerability map: low, medium, and high.*

***Table 4:*** *The coordinates of sample collection stations*

| Sample Location | Latitude | Longitude |
|---|---|---|
| Ozoro | 5$^0$54’0”N | 6$^0$22’0”N |
| Owhelogbo | 5$^0$59’0”N | 6$^0$20’0”N |
| Ellu | 5$^0$59’0”N | 6$^0$29’0”N |
| Ofagbe | 5$^0$58’0”N | 6$^0$43’0”N |
| Emevor | 5$^0$61’0”N | 6$^0$22’0”N |
| Oto-Owhe | 5$^0$57’0”N | 6$^0$23’0”N |
| Iyede | 5$^0$48’0”N | 6$^0$29’0”N |
| Okpe Isoko | 5$^0$52’0”N | 6$^0$35’0”N |
| Arede | 5$^0$61’0”N | 6$^0$31’0”N |
| Oyede | 5$^0$46’0”N | 6$^0$25”0”N |

***Heavy metal contamination of groundwater supplies in the research area***

The detection of lead poisoning can be challenging because lead toxicity is unlikely to be detectable by sight, smell, or fragrance. Given such concentration, it is likely that the environment contains toxic wastes, maybe from aerosol cans, dead battery cells, and other hazardous materials that have been inappropriately disposed of in landfills. The excessive drinking of Pb-contaminated water poses considerable health risks. Inhibition of red blood cell synthesis, which carries oxygen to every area of the body system, is one of the main outcomes, along with brain damage and kidney failure. Its frequent in-take shows no sign until the body's concentration reaches a deadly level before symptoms appear. Studies by Hartono and Pretiwi (2021), Madushika et al. (2023), and WHO (2017) have found other health impacts from excessive consumption of Pb2+, including abdominal pain, weight loss, weariness, diarrhea, vomiting, and hearing loss (see table 5 below for heavy metal test result from water samples). Some of the samples had iron (Fe) concentrations that were greater than the NSDWQ and WHO recommended levels. The maximum amount of iron that can be present in drinking water is between 1.0 and 3.0 mg $l^{-1}$, as stated in WHO (2017). Any amount above this indicates that the water is unsafe to consume since it leaves a bitter and unpleasant taste in the mouth. Goitre in adults is also associated with drinking water that has more iron than expected.

***Table 5:*** *Shows the levels of heavy metal intrusion in the water samples*

| Sample Area | | Lead | Zinc | Iron | Ca | Cr | Hg | Na | K | Mg |
|---|---|---|---|---|---|---|---|---|---|---|
| Ozoro | 0.06 | 0.12 | 0.23 | 0.43 | 4.38 | 0.00 | 0.00 | 0.168 | 0.433 | 0.169 |
| Owhelogbo | 0.08 | 0.18 | 0.24 | 0.41 | 3.24 | 0.00 | 0.00 | 0.172 | 0.436 | 0.162 |
| Ellu | 0.03 | 0.17 | 0.23 | 0.41 | 3.45 | 0.00 | 0.00 | 0.183 | 0.433 | 0.188 |
| Ofagbe | 0.07 | 0.13 | 0.21 | 0.31 | 3.61 | 0.00 | 0.00 | 0.177 | 0.235 | 0.167 |
| Emevor | 0.07 | 0.11 | 0.24 | 0.31 | 6.28 | 0.00 | 0.00 | 0.165 | 0.445 | 0.132 |
| Oto-Owhe | 0.09 | 0.12 | 0.22 | 0.35 | 4.39 | 0.00 | 0.00 | 0.154 | 0.556 | 0.168 |
| Iyede | 0.08 | 0.18 | 0.25 | 0.39 | 3.58 | 0.00 | 0.00 | 0.166 | 0.432 | 0.167 |
| Okpe Isoko | 0.06 | 0.15 | 0.26 | 0.43 | 19.21 | 0.00 | 0.00 | 0.154 | 0.451 | 0.163 |
| Arede | 0.08 | 0.11 | 0.24 | 0.38 | 10.25 | 0.00 | 0.00 | 0.161 | 0.554 | 0.154 |
| Oyede | 0.09 | 0.16 | 0.22 | 0.39 | 7.59 | 0.00 | 0.00 | 0.155 | 0.561 | 0.149 |
| WHO STARDARD | 2 | 0.01 | 5.0 | 0.3 | 200 | 0.01 | 0.01 | 5.0 | 5.0 | 2.0 |
| NSDWQ | 1.0 | 0.01 | 5.0 | 0.3 | 250 | 0.01 | 0.01 | 5.0 | 5.0 | 2.0 |

The values for the heavy metal parameter's incursion in the study were calculated from table 3, and their exceptional values were obtained. Places like Oyede (0.09), Otor-Owhe (0.09), Iyede (0.08), and Owhelogbo (0.08) have higher values than others in the Cu (Ppm) range of 0.03 to 0.09. However, all still fall inside the fundamental guidelines for safe drinking water that are described in (Wu & Sun, 2016) and (NSDQW, 2007). The range of lead (PPM) levels is 0.11 to 0.18, with higher values seen in Owhelogho (0.18), Iyede (0.18), and Ellu (0.17). Iron (PPM) readings range from 0.31 to 0.43, with noteworthy levels observed at every location that are only a little bit above the 0.3 WHO and NSDWQ average. This implies that iron oxide's infiltration into subterranean water can be explained by its correlation and interaction with the host rock components in which it is stored and transferred (Plummer et al., 2020). Adults are more susceptible to the effects of the pollution than are infants and neonates (Wu and Sun, 2016). Excessive iron intake raises the risk of conditions such as Parkinson's, hyperkeratosis, Alzheimer's, diabetes mellitus, abnormal pigmentation, and issues with the kidneys, lungs, liver, and nervous system (Ghosh et al., 2020). Along with affecting the body components involved in birthing, fatigue, weight loss, joint pain, and poor intuition, it can also lead to pancreatic illness, diabetes, and damage to the liver and heart system over time (Hossain et al., 2023). This finding is consistent with the findings of (Ekenta et al., 2015; Ojiako et al., 2018; Ghosh et al., 2020; Kamble, 2020; Omorogieva et al., 2022 and Hossain et al., 2023). Iron and lead contamination distribution maps from the research region are shown in figures 13 and 14. Since the values of other measures are not more extensive than the important values relevant to the WHO and NSDWQ, there is no health risk to consumers.

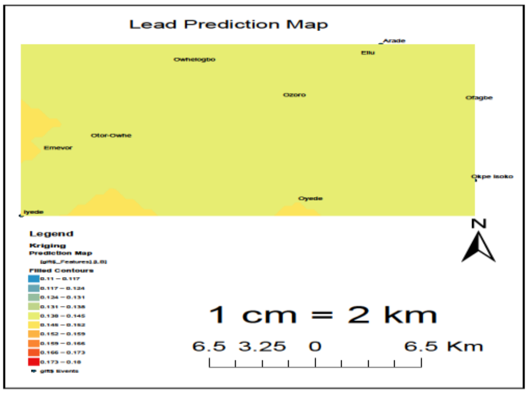


***Figure 13:*** *Lead contaminant dispersion map in the Isoko Norh LGA*

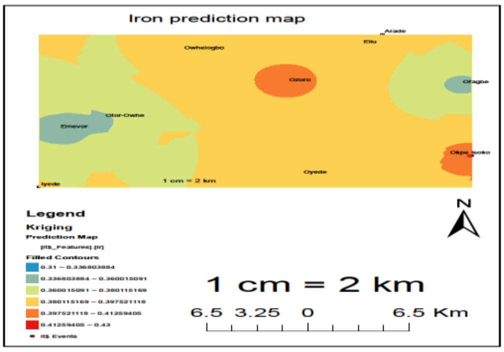


***Figure 14:*** *Iron contamination spread map in Isoko North LGA*

***Index of Heavy Metals (MI)***

An indexing tool known as the Heavy Metal Index (MI) was developed to determine the degree of heavy metal contamination in groundwater resources. It is used to confirm how heavy metals affect groundwater sources. The indexing approach for evaluating water pollution by heavy metal resources was used to validate these heavy metal data from the research location. For each of the ten boreholes, the mean concentration values (Ci) for the metals under analysis were first ascertained. Heavy metal values were multiplied by 1000 to determine the mean concentration of hazardous metals, which was expressed in parts per billion. These results show that local boreholes contain considerable levels of heavy metals.

The Heavy Metal Index (MI) was then computed using the following formula, which was based on WHO guidelines for the maximum acceptable concentrations (MAC) of the observed metals:

$$MI = (\sum Ci/MAC) \quad (1)$$

MAC stands for Maximum Allowable Concentration, and Ci is the mean concentration. To save space, the metal index values for each borehole were determined independently, and the results are shown in table 6 below (a similar exercise was described in Nkwunonwo et al. 2024).

***Table 6:*** *Information about the specimens' classification according to the Heavy Metal Index (MI)*

| S/No. | Sample Locations | ∑Ci/MAC | Class | Properties |
|---|---|---|---|---|
| **1** | Ozoro | 0.84822 | II | Pure |
| **2** | Owhelogbo | 0.89356 | II | Pure |
| **3** | Ellu | 0.872 | II | Pure |
| **4** | Ofagbe | 0.697340 | II | Pure |
| **5** | Emevor | 0.71612 | II | Pure |
| **6** | Otor-Owhe | 0.80256 | II | Pure |
| **7** | Iyede | 0.87742 | II | Pure |
| **8** | Okpe-Isoko | 0.94134 | II | Pure |
| **9** | Aradhe | 0.839 | II | Pure |
| **10** | Oyede | 0.88706 | II | Pure |

However, heavy metal indexing testing for contamination in subsurface water revealed a class 'II' result Nkwunonwo et al. 2024, meaning that all examined specimens had a "pure" result for heavy metal intrusion. However, when pivoted to the next whole number, the Ci/MAC ratios indicate a significant increase in pollution in every sample from that class, placing them in the "class III" contamination class, which denotes "slightly contaminated" water samples. This is consistent with the results of the specimen studies, which showed that lead and iron were the only components with minor compositional variations beyond the WHO and NSDWQ standards for drinkable water quality. As a result, the result can be considered satisfactory.

***Pairwise analysis from AHP***

The findings of the groundwater potentials and vulnerability assessment level of the research region were verified using the AHP Pairwise analysis program. A popular approach, it reflects human judgment in MCDM (Multiple Criteria Decision Making). A complex unstructured problem must be broken down into its component pieces in a hierarchical sequence. To arrive at a scale of preferences among a collection of choices, it used a pairwise comparison technique. Rainfall, height, slope, drainage density, lineament density, land use and land cover (LULC), and geology are among the elements that were examined. According to the findings, the two primary influencing elements that cause heavy metal contamination of the local groundwater are geology (23.79%) and rainfall (25.78%). This was accomplished by inputting the variables under study into the program. The program then used the values to produce a set of values that reflected the hierarchical order that influences the groundwater potential in the study area, keeping in mind that the consistency ratio (CR) could not be higher than 10%. Consistency greater than 10% is regarded as invalid. Table 7 and Figures 15 depicts the order of importance as well as a matrix of distribution based on hierarchic relevance.

***Table 7:*** *Component distribution matrix in hierarchical order*

| Matrix | | Rainfall | Geology | Geomorphology | Lineament Density | Drainage Density | Elevation | Slope | LULC | 0 | Normalized Principal Eigenvector |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | - | |
| Rainfall | 1 | 1 | 1 | 3 | 6 | 5 | 3 | 2 | 3 | - | 25.88% |
| Geology | 2 | 1 | 1 | 3 | 6 | 5 | 3 | 2 | 1 | - | 23.79% |
| Geomorphology | 3 | 1/3 | 1/3 | 1 | 3 | 3 | 3 | 2 | 1 | - | 13.05% |
| Lineament Density | 4 | 1/6 | 1/6 | 1/3 | 1 | 2 | 3 | 2 | 1 | - | 8.61% |
| Drainage Density | 5 | 1/5 | 1/5 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | - | 5.31% |
| Elevation | 6 | 1/3 | 1/3 | 1/3 | 1/3 | 1 | 1 | 3 | 1 | - | 7.39% |
| Slope | 7 | 1/2 | 1/2 | 1/2 | 1/2 | 1 | 1/3 | 1 | 1 | - | 6.67% |
| LULC | 8 | 1/3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | 9.29% |

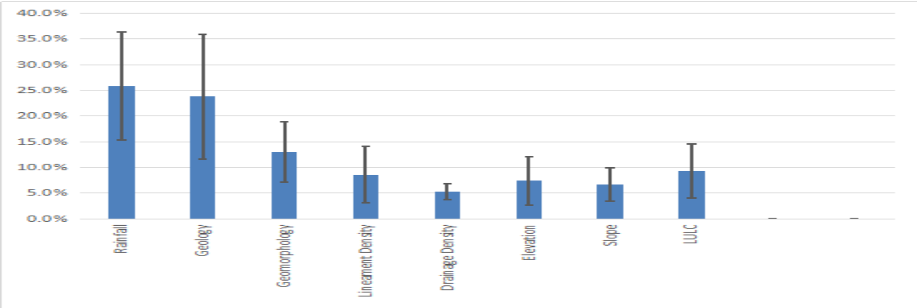


***Figure 15:*** *Hierarchical graphical representation of the study's components*

## 4. Conclusion

Groundwater invasion by heavy metals presents serious health and environmental risks, and managing it piques a variety of interest in both study and policy. A lack of adequate management and control systems to uphold the requirements of the borehole drilling standard, which, among other strict measures, requires that a laboratory test be performed following the drilling process to determine any potential levels of pollution, will lead to an epidemic of feature health. This study used drill specimens and basic data sets intended to detail spatiotemporal aspects in order to reach a pertinent conclusion. The location's topographic features were evaluated with the help of geospatial maps created with ArcGIS software. Demographic elevation maps (DEM), iron and lead contamination prediction maps, and route maps showing sampling locations were made to help with comprehension. This is necessary since it helped to clarify the true effects of pollution infiltration in the study area. The study's findings showed that the intensity of the contaminants is continuously increasing and that, because the boreholes are relatively recent, further leaching of these chemicals into the area below will eventually result in a rise in the materials' concentration harming the water's quality. This study has looked at important concerns related to groundwater contamination from Isoko North LGA and the environs of Delta State, Nigeria, using geospatial analysis and a tripartite assessment of the quality of groundwater resources. Determining the groundwater's sensitivity model to floodwater invasion and the sort of management that is appropriate for the region is the main goal. The geospatial data was designed using the Hierarchical Analytic Process (AHP) using ArcGIS 10.8 software; the study's interest in using AHP is based on the influence of geology and rainfall. In order to describe the geographical characteristics of the study topic and other underlying topographical aspects, this study used water samples from 10 boreholes in Isoko North LGA as well as other data sets. According to the area's elevation outline, the majority of the region is low, only 2 meters above sea level. Because the entire area is considered vulnerable due to its low nature, groundwater flow extends throughout the area. 75.5% of the region is classified as very vulnerable, 17.22% as moderately vulnerable, and 7.29% as lowly vulnerable, according to the vulnerability model of the region, which was created using a weighted overlay based on GIS. These results highlight the health and socioeconomic issues that heavy metal invasion and aquifer ecosystem degradation will have for the local people and households who depend on groundwater for drinking and other household needs. Therefore, it is crucial that the organizations in charge of regulating consumable water resources also effectively oversee this industry in order to prevent health issues linked to the intake of heavy metals in groundwater. The quality of water from a recently dug borehole must be determined through laboratory testing before use.

### Declaration

The design of this study is based on the structure and backdrops provided by all previous studies, which the authors have acknowledged. We express our gratitude to the blind reviewers and the handling editor of this manuscript/journal.

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