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Application of DRASTIC Model in the Mapping of Groundwater Pollution and Vulnerability in College of Education Warri, Nigeria

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Abstract

Pollution of groundwater is a serious issue because aquifers are susceptible to contamination from land use including indiscriminate dumping of refuse and other industrial waste. Vulnerability assessment is an essential step in assessing groundwater contamination. DRASTIC model was adopted for the venerability assessment of Groundwater in College of Education Warri in Delta State. Electrical resistivity method was used to determine some of the DRASTIC variables. The result showed that the depth to water table varies from 40-90m in the study area, the net recharge varied from 1110-1987 mm/day, Soil Media was found to be friable sand stone to clayey Sandstone, Topography was 80-90 ft with slope range of 1º to 2° , Impact on Vadose was moderate and Hydraulic Conductivity was 0.94-2.1 Gal/Day. The vulnerability index findings of the area was from 100-150 which showed that the west and the south-south portion of the area are highly prone to contaminant infiltration. Result of the geochemical analysis of groundwater and soil in the area was used to validate the DRASTIC model result and the two results agree.

***Keywords**: DRASTIC model, groundwater vulnerability assessment, pollution, geospatial distribution of contaminants*

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1 Introduction

Groundwater is stored in aquifers, which not only provide water source through extraction (e.g., pumped wells), but aquifers also contribute to surface waters such as rivers and lakes (Schwartz and Zhang, 2003). The global challenge of ensuring access to safe and high-quality drinking water is well recognized (Iqbal et al., 2023). Unfortunately, across the globe, groundwater has been significantly degraded by the human population through unsustainable use and contamination (Morris et al., 2003). Consequently, researchers have expressed significant concerns regarding groundwater contamination, which can arise from various human activities, including storage tank leakage, chemical leaks, landfills, fertilizer and pesticide use, inadequate sanitation systems, and untreated sewage and waste discharge (Kalhor et al., 2019; Chamanehpour et al., 2020). In particular the Area of study is dominated by lots of students and staffs activities resulting from wastes generated on a daily basis. Also, there is a fuel station and generating sets emitting harmful emission into the environment and the soil and groundwater in the Area. Bad quality water and inadequate water supply have accounted for a number of preventable diseases in many communities across the world. These factors have also affected agriculture in terms of the types of crops grown and yield as well as animals (Saeed and Khan, 2014). Many countries of the world which hitherto have enough water are now experiencing drought, leading to food shortages, famine and starvation in those areas which have affected the economic future of Nations. Consequently, many nations have now concentrated on groundwater as a reliable source of quality water (Fetter, 2007; Anomohanran, 2014). Many people also contribute to the shortage of quality water through the way and manner water source are handled and the way we keep our environment. In other words, the people are making more of the water that is available for use unfit. The water in the world is limited while population is rising. Only about 2.5% of the world's water is not salty and two third of this is locked up in the icecaps and glaciers (Fetter, 2007). Anomohanran (2013), asserted that even though the world and nature has endowed with so much water, pollution has continued to make good quality water unavailable for use. Some of these polluted water results from man's use of the environment such as the way we disposed our waste to leakages from sewage and leakages from underground oil pipes found in parts of the oil rich Niger Delta. Other identified sources of groundwater pollution are agricultural chemicals and wastes. Aquifer protection is essential for sustainable use of groundwater resources. The quality of groundwater is under a considerable potential of contamination especially in industry dominated areas with intense activities that involve the excessive use of fertilizers and pesticides. Vulnerability assessment is a major techniques used in the development of groundwater protection strategies. It allows delineation of areas with different degree of natural protection of groundwater against pollution (Farjad et al. 2012; Gogu et al. 2000). Abdulrafiu et al. (2016) carried out vulnerability studies of groundwater with special focus on the impacts of dumpsite activities and the associated risk on both the environment and human using DRASTIC model. The result proved that the model is a good tool in groundwater vulnerability assessment. The model uses six parameters/variables (D- Depth to water, R- Net Recharge, A- Aquifer media, S- Soil media, T- Topography, I- Vardose zone, and C- Hydraulic conductivity). These variables give information about the hydrogeological setting that gives indication of susceptibility of groundwater in an area to pollution. Apart from DRASTIC model, Salufu et al. (2022) have used Legrand correlation to assess the vulnerability of groundwater in Ebhoakhuala, Ekpoma and Agbede, Edo State, Nigeria with appreciable result when validated with hydrogeochemical data of the area. However, this method is not as effective as DRASTIC model and Legrand correlation. A number of hydrogeological and spatial attributes need to be assessed including water table depth, aquifer properties, topography and other relative variables. All spatial attributes with their particular ranks and weights are combined to produce a final index value using an appropriate algorithm that defines groundwater vulnerability. Groundwater vulnerability maps provide useful information to protect groundwater resources and to evaluate the potential for water quality improvement with changes in industrial practices and land use applications (Voudouris et al. 2010).

One of the ways to determine aquifer protection is the Geophysical methods. This is used to determine the thickness of the subsurface formations and to determine the materials they consist of (Ayolabi et al., 2009; Okiongbo et al., 2011; Anomohanran, 2013). The geophysical method commonly used is the electrical resistivity method. This method probes far into the subsurface and determines the occurrence or otherwise of groundwater and its quality and quantity through the measurement of resistivity values (Ayolabi et al., 2010). The simplicity and cost effectiveness of the electrical resistivity method has led many researchers to adopt it carrying out their various investigations on groundwater. (Ujuanbi and Asokhia, 2005; and Anomohanran, 2013). However, the present research focuses on using DRASTIC model to assess the vulnerability of groundwater of College of Education campus in Warri, Delta State, Nigeria. This study is very important because the large population of Students and Staffs in the Institution that depend on the only borehole in the campus. Wastes are generated on daily basis and most of these wastes are gathered in a dumpsite close to the functional borehole within the Institution before they are taken away by the waste management authority of Warri south Local Government Authority. Also there is a Petroleum Filling station in the premises where a lot of Petrol and Diesel are often spilled due to equipment failure or mal-handling of the equipment resulting to possibility of some of these harmful substances infiltrating the soil into the ground water. Thus this study is very crucial in order to ascertain the safety of the students and staff.

2 Study Area

The College of Education is located in the heart beat of Warri in the south south zone of Nigeria. It is bounded to the east by Ughelli, to the north by Abraka and Sapelle, and to the south west and south by Atlantic Ocean (Figure 1). There have been a lot of study activities in College of Education Warri. Owing to the large population of Students and Staffs in the Institution, waste are generated on daily basis and most of these wastes are gathered in a dumpsite (Figure 2) within the Institution before they are taken away by the waste management authority. Also a Petroleum Filling station is located (Figures 3-4) in the premises where a lot of organic wastes (Petrol and Diesel) spill due and infiltrate the groundwater.

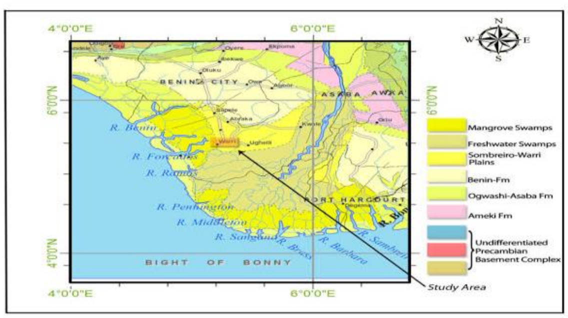

Figure 1. Map of the study Area (College of Education Warri) (Generated from Google maps)

Figure 2: Photo of Dump Site in College of Education Warri with Traces of Polluted Environment.

Figure 3: Photo of Storage Tank of Filling Station in College of Education Warri with Traces of Polluted Environment.

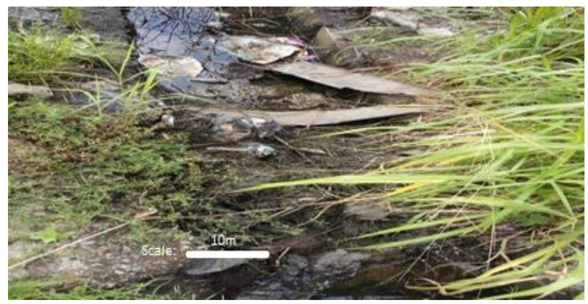

Figure 4: Polluted Environment Close to Filling Station in College of Education Warri.

3 Materials and Methods

Materials and Methods

The study methods involved both the invasive and non-invasive method of investigation. The invasive method involved the collection of water samples and soil samples and water samples from the borehole geochemical laboratory analysis to validate DRASTIC model which is the non-invasive results. The non-invasive method involved two phases of measurements, the hydro-geologic and geophysical measurement. The DRASTIC model which was developed in USA for the purpose of protecting groundwater resources (Aller, Bennett, Lehr, Petty and Hackett, 1987) was used for the purpose of this research. DRASTIC is an empirical groundwater model that estimates groundwater contamination vulnerability of aquifer systems based on the hydro-geological settings of the area. A hydrogeological setting is defined as map able unit with common hydrogeological characteristics (Engel, Navulur, Cooper, Hahn, 1996). The DRASTIC model helped to assess the groundwater vulnerability of the study area. While Geographic Information Science (GIS) was used to generate the geospatial distribution of the DRASTIC model's parameters for easy vulnerability study of the area.

3.1 Theoretical Framework

The resistivity measurements phase involved the use of Schlumberger depth sounding (Zohdy, Eaton, and

Mabey, 1974; Patra and Nath, 1998) as shown in figure 5. The depth sounding data were presented as sounding curves as shown in Figure 5 below. The field data was inverted Res1D inversion model according to Least square inversion model. The resistivity method was used to determine some of the DRASTIC model variables such as the water table, aquifer media, hydraulic conductivity, and soil media

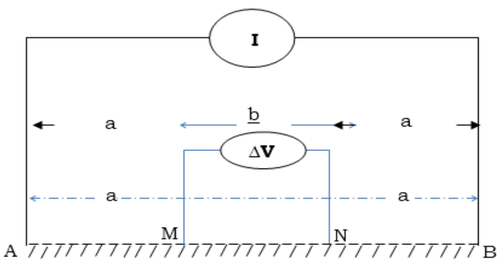

Fig. 5. Schlumberger array

Considering a Schlumberger electrode arrangement as shown in Figure 1, the outer electrodes A and B are referred to as current electrodes while the inner electrodes M and N are the potential electrodes. Therefore from the equation:

$$V=IR \qquad (1)$$

[From Ohm's law in Electricity]

$$R=\frac{\rho L}{A} \qquad (2)$$

$$\rho_a = K.R \qquad (3)$$

Where: $K=\pi(a^2-b^2)/b$ Schlumberger array

$a=\frac{AB}{2}$ (half-current separation distance) value in metre, $b=\frac{MN}{2}$ (half-voltage separation distance) value in meter, k= geometric factor.

V=voltage, I=current, R=Resistance, L=Length, A=Cross-sectional Area.

4 Results and Discussion

The result of the inversion model (Figure 6- Figure 8) for the resistivity data acquired in the study area showed that the water table in the study area varies from 40m to 90m. The result shows that the soil formation is a friable sandstone and clayey consolidated sandstone.

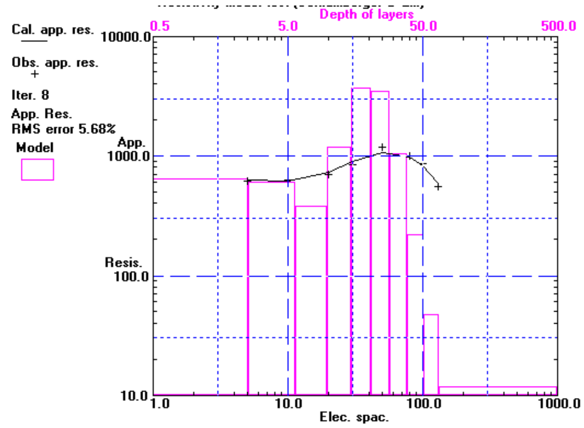

Figure 6. Inversion Model of resistivity result for VES 1 acquired at College of Education Warri

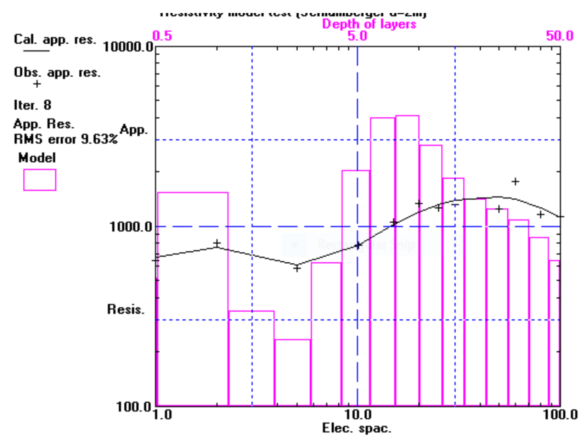

Figure 7. Inversion Model of resistivity result for VES 2 acquired at College of Education Warri

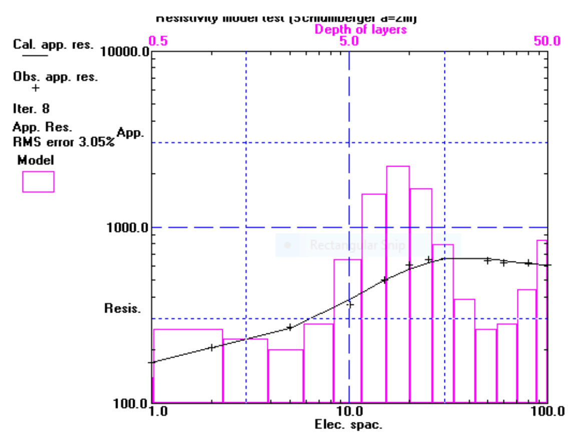

Figure 8. Inversion Model of resistivity result for VES 3 acquired at College of Education Warri

4.1 DRASTIC Model

Spatial distribution of inversion model of the study area shows that the south-south portion has the shallowest water table of 40m to 60m as shown in Table 9. The deepest area occurs at the boundary of the study area (Figure 9).

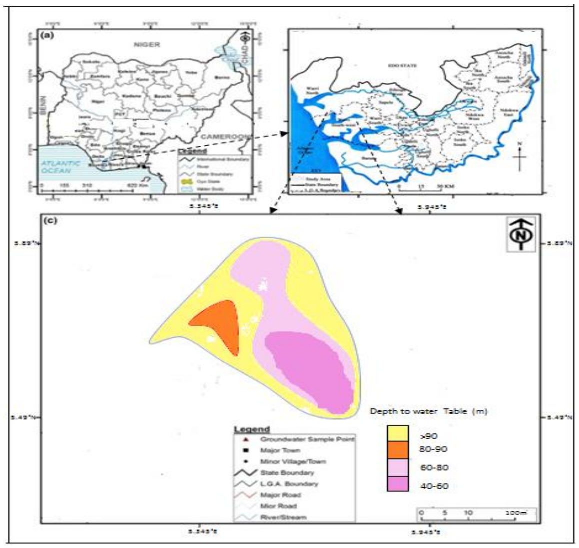

Figure 9. Spatial Results of Depth to Water Table for College of Education Warri

The aquifer recharge in the area is almost uniform with a value of 1987 m/year. However, the north central has the lowest aquifer recharge with a value of 1110 m/year (Figure 10). Friable sandstone dominates the west and the north central to the south-south of the study area (Figure 10) compare to the other portion of the study area that is highly clayey.

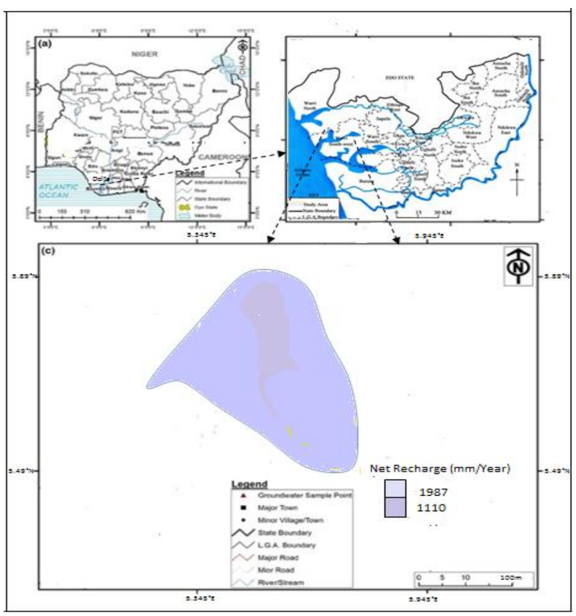

Figure 10. Spatial Results of Net Recharge for College of Education Warri

The surface elevation of the study area is generally low, ranging from 80 to 90 ft (Figure 12) with slope of 1º to 2º. The topography is generally flat and low. The hydraulic conductivity of the area is observed to be 0.94-2.1 Gal/day (Figure 13). The south-south and west portion of the study area have the highest hydraulic conductivity (2.1 Gal/Day)

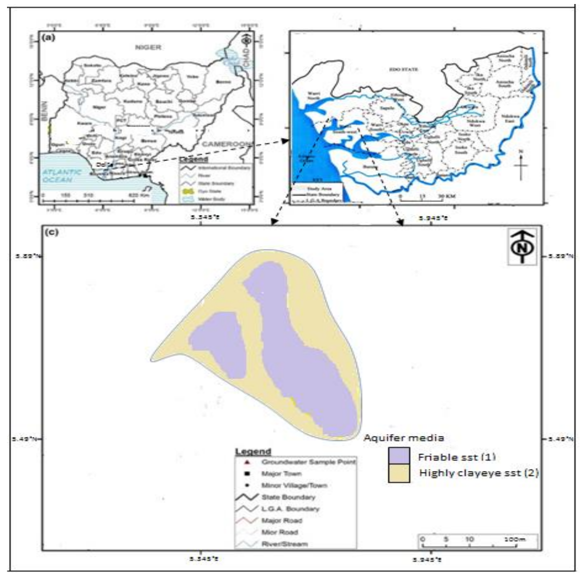

Figure 11. Spatial Results of Aquifer Media for College of Education Warri

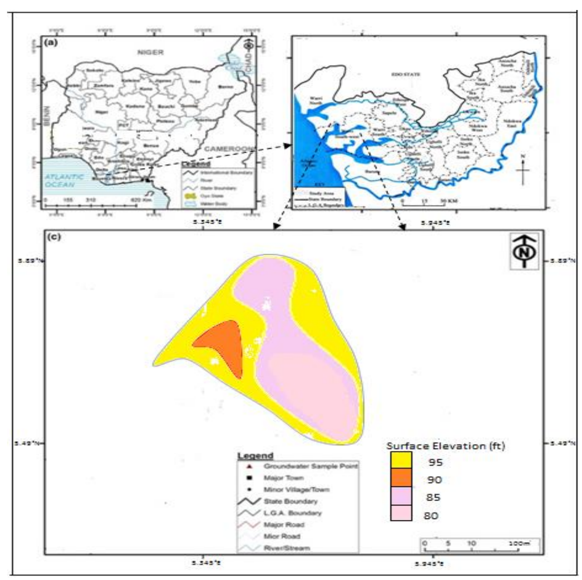

Figure 12. Spatial Results of Topography for College of Education Warri

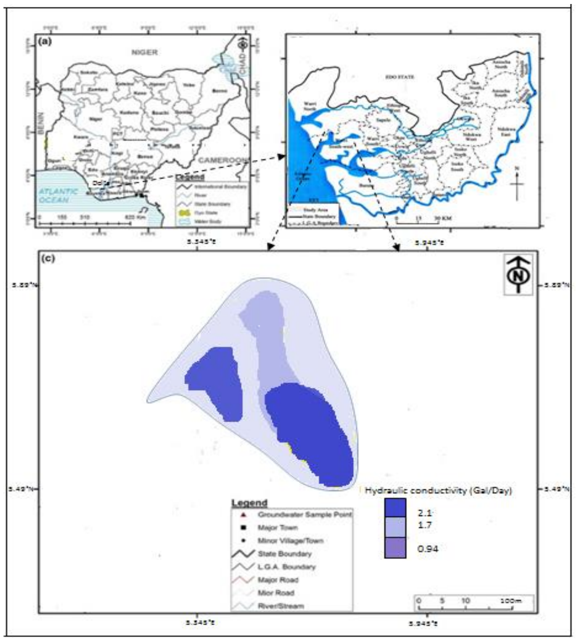

Figure 13. Spatial Results of Hydraulic Conductivity for College of Education Warri

4.2 Groundwater Vulnerability of the Study Area

The vulnerability map generated by the GIS using DRASTIC parameters acquired from the geophysical, hydrogeological, and geological field data, obtained from the study area shows that the aquifer that underlies the study area has heterogeneous sensitivity to contaminants infiltration into the aquifer in the area.

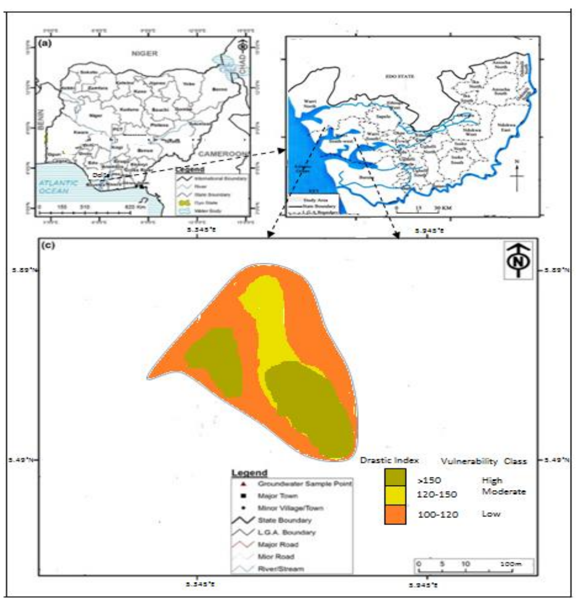

Figure 14. Spatial Results of Vulnerability Index for College of Education Warri

The sensitivity of the area was cumulatively determined by the seven DRASTIC parameters by imputing them into the DRASTIC model to determine the vulnerability index of the area. The vulnerability index of the area ranges from 100 to 155 in the entire area (Figure 14) toward the extreme south west, and the central to south-south, have the highest vulnerability index of over 150 suggesting high vulnerability case. It means that the groundwater in these areas is highly prone to contamination. However, the lowest vulnerability index of the range occurs in the extreme border, bordering the study area. This implies that the sensitivity of aquifer that underlies the boundary of the study area compares to the aquifers that underlie other part of the area is very low (See Table 1). This indicates that the potential of aquifers in those areas to contaminants infiltration is low.

Table 1. Drastic index and vulnerability class

S/N	DRASTIC index	Vulnerability class
1	>88-100	Very low
2	>100-125	Low
3	>125-150	Moderate
4	>150-200	High
5	>200-221	Very high

4.3 Validation of DRASTIC Model

The result of the geochemical analysis of water samples in the south west and part of the central north to the south-south of the study area of the north have high concentration of oil and grease 0.25 mg/L and 0.51 mg/L (Table 2), respectively while other part of the area show insignificant concentration. Similarly, there is high concentration of sulfate (4.53 mg/L and 4.34 mg/L) and nitrates (22.17mg/L and 25.42 mg/L) compare to other parts of the study area as shown in Table. The presence of high concentration of nitrate and sulfate suggests infiltration of organic materials from the surface into the aquiferous unit. The infiltration is as a result of the porous soil media, high hydraulic conductivity, shallow water and aquifer media. The result of the geochemical water analysis validates DRASTIC index result for the entire area.

The geochemical result of the soil samples throughout the study area show presence of heavy metals with high concentrations (Table 3). The concentration must have been originated from the hydrocarbon infiltration from the filling station. It strange, in the aquiferous layer, there is presence of grease and oil stains but the heavy metals concentrations were insignificance compare to the soil samples. The presence of heavy metal suggests oil spills on the surface maybe from the nearby filling station. However, there is no evidence of infiltration into the aquiferous unit except the oil and grease.

Table 2. Physicochemical properties of groundwater from boreholes in College of Education, Warri

Parameters	1	2	3	4	5	Mean
Temp °C	28.56 ±1.21	26.98 ± 1.4	27.78 ± 0.23	29.36 ± 0.58	26.33 ± 0.82	27.80 ±1.21
p H	5.91 ±0.79	5.88 ± 0.48	5.64 ± 0.27	4.86 ± 0.33	7.88 ± 0.13	6.03± 1.12
EC µ/cm	76.29 ± 65.77	70.96 ± 65.37	214.6 ± 87.54	220.14 ± 85.62	61.83 ± 9.52	128.76 ± 81.07
Hardness, mg/L	2.03 ± 0.86	1.51 ± 0.43	49.73 ± 66.98	54.65 ± 67.56	12.76 ± 3.42	24.14 ±26.06
Dissolved oxygen, mg/L	3.48 ± 0.76	3.28 ± 0.92	4.11 ± 0.57	4.06 ± 0.57	2.56 ± 1.14	3.50 ± 0.64
TDS, mg/L	41.96 ±36.18	39.28 ±35.96	118.03 ± 48.14	121.08 ±47.09	34.01 ± 5.26	70.87 ± 44.55
Nitrate, mg/L	1.26 ± 1.24	1.32 ± 1.24	22.17 ± 23.26	25.42 ±22.84	0.19 ± 0.28	10.07± 12.59
Sulphate, mg/L	0.9 ±0.5	0.89 ± 0.48	4.53 ±4.68	4.34 ± 4.69	0.71 ± 0.41	2.27 ± 1.98
Chloride, mg/L	3.66 ±2.78	3.56 ± 2.76	24.41 ± 29.12	28.78 ± 29.61	7.26 ±5.21	13.53 ± 12.11
Oil & Grease, mg/L	0.0003 ±0.0004	0 ± 0	0.24 ± 0.53	0.51 ± 0.67	0 ± 0	0.15 ± 0.23
Lead, mg/L	0.005 ± 0.005	0.0038 ± 0.004	0.007 ± 0.008	0.014 ± 0.011	0.003 ± 0.002	0.007 ±0.004
Chromium, mg/L	0.003 ±0.005	0.0004 ± 0.001	0.0024 ± 0.004	0.004 ± 0.006	0.001 ± 0.001	0.002 ±0.002
Manganese, mg/L	0.06 ± 0.056	0.038 ±0.031	0.05 ± 0.022	0.064 ± 0.03	0.001 ± 0.001	0.043 ±0.025
Cadmium, mg/L	0.013 ±0.013	0.008 ±0.008	0.008 ± 0.004	0.009 ± 0.008	0.001 ± 0.002	0.008 ±0.004
Nickel	0 ± 0	0 ± 0	0.004 ± 0.009	0.009 ± 0.013	0 ± 0	0.003 ± 0.004
Copper mg/L	0.033 ± 0.042	0.026 ± 0.042	0.062 ± 0.046	0.071 ± 0.051	0.027 ± 0.036	0.044 ± 0.021
TCC	4.71 ± 3.27	6.2 ± 4.03	14.4 ± 8.39	12.71 ± 7.57	4.32 ± 4.64	8.47 ± 4.73
FCC	0.71 ±0.89	0.8 ± 0.84	2.6 ± 2.07	1.71 ± 1.3	0.67 ± 0.89	1.3± 0.84

Note: Data are Means ± Standard Deviation of replicate (n = 2) analyses. 5 sampling locations

Table 3. Concentration of Heavy metals in soil samples in College of Education, Warri (2023)

Parameter	SS1 (0-15cm)	SS2 (0-15cm)	SS3 (0-15cm)	SS4 (0-15cm)	Mean
Lead, mg/kg	0.001 ± 0.001	0.001 ± 0.001	0.001 ± 0.001	0.001 ± 0.001	0.001 ± 0.000
Iron, mg/kg	1336.999 ±1.184	1149.292 ± 0.759	1806.082 ± 2.109	1541.537 ± 0.089	1458.478 ± 281.709
Chromium, mg/kg	0.001 ± 0.001	0.001 ±0.001	0.001 ±0.001	7.859 ± 0.005	1.966 ± 3.929
Manganese, mg/kg	44.328 ± 0.095	28.269 ± 004	56.221 ± 0.677	41.047 ± 0.006	42.466 ± 11.493
Cadmium, mg/kg	0.001 ± 0.001	0.001 ± 0.001	0.002 ± 0.001	0.001 ± 0.001	0.001 ± 0.001
Copper, mg/kg	11.571 ± 0.561	7.714 ± 0.129	7.749 ± 0.105	11.076 ± 0.016	9.5275 ± 2.084
Nickel, mg/kg	6.743 ± 0.239	0.001 ± 0.001	10.511 ± 0.227	0.001 ± 0.001	4.314 ± 5.212
Cobalt, mg/kg	0.001 ± 0.001	0.001 ± 0.001	0.002 ± 0.001	0.001 ± 0.001	0.001± 0.001

Note: Data are Means ± Standard Deviation of replicate (n = 3) analyses. SS: Soil samples

5 Conclusion

Vulnerability assessment of groundwater in college of Education, Warri, using DRSTIC model has been successfully carried out. The study has been able to provide empirical information about the vulnerability status of the ground water in College of Education. The study has established that the activities of both students and staffs caused contamination of the surface water but the contaminants are yet to get to the aquifer in some part of the campus while in west and south-south of the area, the contaminants has gotten into the aquifer due to the geology and the hydrogeological setting of the area. The study delineated that the west and south-south of College of Education Warri is prone to high contamination while other areas in the study area have low-moderate contamination potential. The study revealed that the contaminant in the study area is anthropogenic in nature. However, continuous monitoring of the ground water status is recommended in the area.

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