ASSESSMENT OF AQUIFER VULNERABILITY TO CONTAMINATION USING A MODIFIED "LAHBUD" MODEL ("AHBD" METHOD) WITHIN FEDERAL UNIVERSITY OYE-EKITI

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ABSTRACT

Groundwater vulnerability to contamination risk of the peculiarities of Basement Complex terrain underlain with a major rock type has been studied at Federal University of Oye-Ekiti, Ekiti State, Southwestern Nigeria using remote sensing and integrated geophysical methods. Modelling of the study region took into account of forty (40) Vertical Electrical Sounding (VES) points. Landsat 8 and aeromagnetic data were processed for lineament extraction and composite lineament density generation. Four parameters which include depth to Aquifer (A), Hydraulic conductivity (H), Bedrock relief (B) and lineament Density (D) were identified to affect aquifer vulnerability of the region. The Multi-Criteria Decision Analysis (MCDA) in the context of Analytical Hierarchy Process (AHP) was employed for weights of 0.5436 (A), 0.2442 (H), 0.1359 (B) and 0.0763 (D) allocated to each of the parameters accordingly. Normalization of the assigned weight and its consistency was carried out (9.7%). The aquifer vulnerability map ("AHBD" model) of the region was developed. The area was classified into low, moderate and high aquifer vulnerability zones. "AHBD" model was validated with geochemical parameters and the result showed 76% of agreement which justified reliability of the model and the methodology used. Human and constructional activities should be controlled around the high vulnerability zones.

Keywords: Basement complex, Bedrock relief, Landsat 8, Lineament Density, Remote sensing

INTRODUCTION

The management of Federal University Oye-Ekiti (FUOYE) decides to admit more students and accredit new programmes as an aftermath effect of COVID-19 lock down of 2020-2021 academic sessions on Nigeria students. The students generate a lot of waste on campus which could have an adverse effect on the groundwater resources and their health status in the nearest future. Contaminated water can serve as the spread centre for diseases such as typhoid, dysentery, cholera and diarrhea (Hunter et al., 2002; Nicholas, 2004; Olaseeni et al., 2020; Olajide et al., 2020; Coker et al., 2021).

Water is one of the most natural resources used by humans for their domestic, industrial and agricultural purposes (Oladapo and Ayeni, 2013; Naomi et al., 2007; Coker, 2021; John et al., 2020; Melissa et al., 2021). Groundwater is the water that is found within the aquifer system and reservoir beneath the earth surface in the basement complex and sedimentary terrain respectively (Andrew and Philippa, 2022). The extent of deterioration of natural groundwater quality by human and anthropogenic activities can be described as aquifer vulnerability (Mogaji et al. 2014; Olaseeni et al., 2021). Many researchers have worked on groundwater contamination using GIS and geophysical methods (Mogaji et al., 2014; Olaseeni et al., 2020; Akinlalu et al., 2021).

The degree of infiltration of contaminant through the overlying layer above the aquifer systems can be used to control the level of aquifer contamination. Research has shown that permeable overlying layer allows high contaminants penetration while impermeable layer disallowed contaminants to percolate. Hence, the properties and nature of the overlying layers are very essential in groundwater vulnerability assessment. However, Multi-criteria decision analysis is employed for the assessment of aquifer vulnerability of this region. The vulnerability model was based on integrating some important parameters such as depth to aquifer, hydraulic conductivity, bedrock relief and lineament density. Aquifer vulnerability assessment is carried out to reveal high vulnerable zones for contamination depending on human factors and lineament concentrations.

Olaseeni et al., (2020) assessed regional groundwater vulnerability in a Precambrian basement complex with five (5) different rock types and complex land use environment to generate “LAHBUD” Model with validation. They integrate geophysical, remote sensing and GIS methods to derive the modelling algorithm; Lithology (L), depth to Aquifer (A), Hydraulic conductivity (H), Bedrock relief (B), land Use (U) and lineament Density (D). This present area of study is composed of migmatite gneiss and the main land use is for built up with sparse vegetation and two river channels. The two parameters (lithology and land use) have equal or parallel effect on the aquifer vulnerability to contamination of the area and they were removed. "AHBD" model was utilized for the evaluation of the degree of contamination in this study. The vulnerability of the aquifer to contamination within the campus needs to be evaluated as to guide the FUOYE against risk zones for refuse dump location and for massive construction activities that are ongoing.

Location and Geology Settings of the Area

Federal University Oye-Ekiti is located within the Oye Ekiti, Ekiti State, Nigeria. It lies between latitude 7º55'00"N to 7º56'40"N and longitude 8º59'80"E to 8º60'80"E (Figure 1). Two major roads, minor roads leading to different faculties and footpaths provide access to the region. Dry season occur in the area from November to February and March to October are right season for rain. The temperature of the region ranges between 21 ºC and 35 ºC. Migmatite gneiss of Precambrian Rock of Southwestern Nigeria (Figure 2) underlay the area (Rahaman 1988, Bayode et al., 2014; Aroyehun and Akintorinwa, 2008).

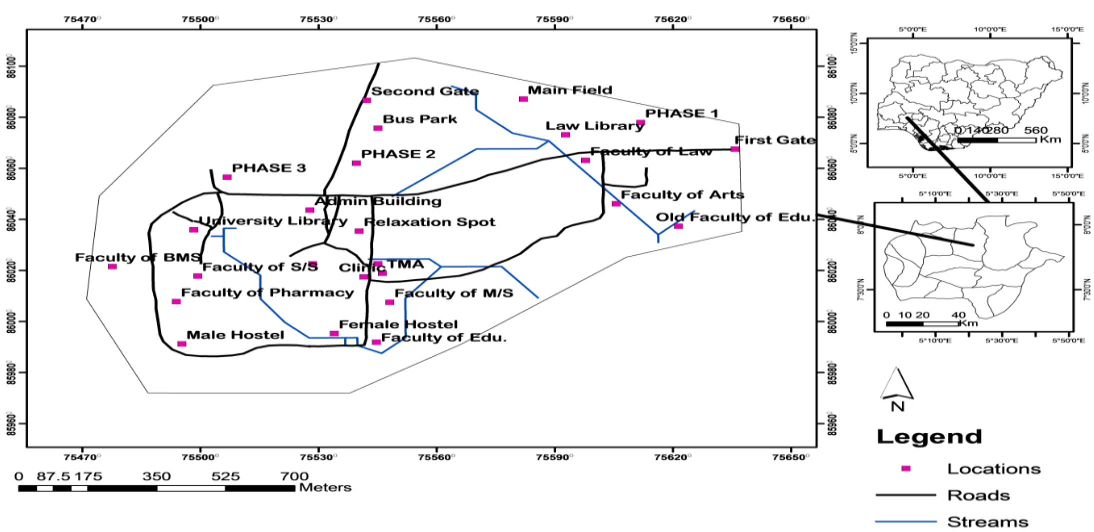

Figure 1: Location map of the study area

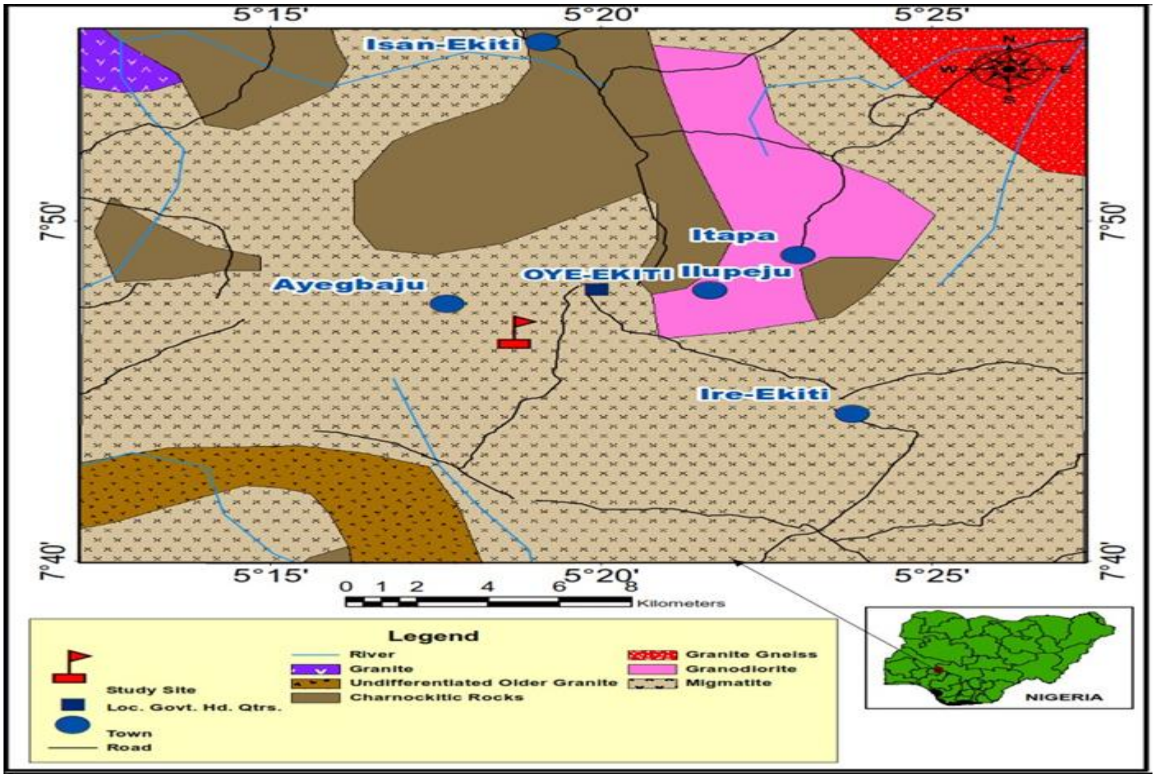

Figure 2**:** Geological map of a portion of Ekiti State showing the study area (Modified from Geological Survey of Nigeria, Akure sheet 61, 2004).

MATERIALS AND METHODS

Landsat 8 imagery, aeromagnetic and vertical electrical sounding data were used for this study. From the websites of NASA, USGS, and the global land cover facility (GLCF), Landsat 8 images of the area were obtained. With the help of an automatic lineament extractor, lineament concentrations were extracted from the picture that was covering the area. Fuoye Aeromagnetic Map (sheet 244) was procured from the Nigeria Geological Survey Agency (NGSA), Abuja. Total magnetic intensity (TMI) data were interpreted using the Oasis montajTM 7.5 software and different signal-improving approaches, including analytic signal, first vertical derivative, and total horizontal derivative, were applied to improve signal and delineate lineament. Forty (40) vertical electrical soundings (VES) data were collected using Ohmega earth resistivity meter (Figure 3). Tables and maps were created by processing and interpreting VES data. The "AHBD" model's four parameters- depth to aquifer (A), hydraulic conductivity

(H), bedrock relief (B), and lineament density (D)-were created by combining remote sensing and geophysical data. The aquifer susceptibility to contamination was evaluated using the "AHBD" model. In order to validate the created model, composition studies of nitrate, calcium, and magnesium elements were also carried out on seventeen (17) water samples from boreholes (Figure 4).

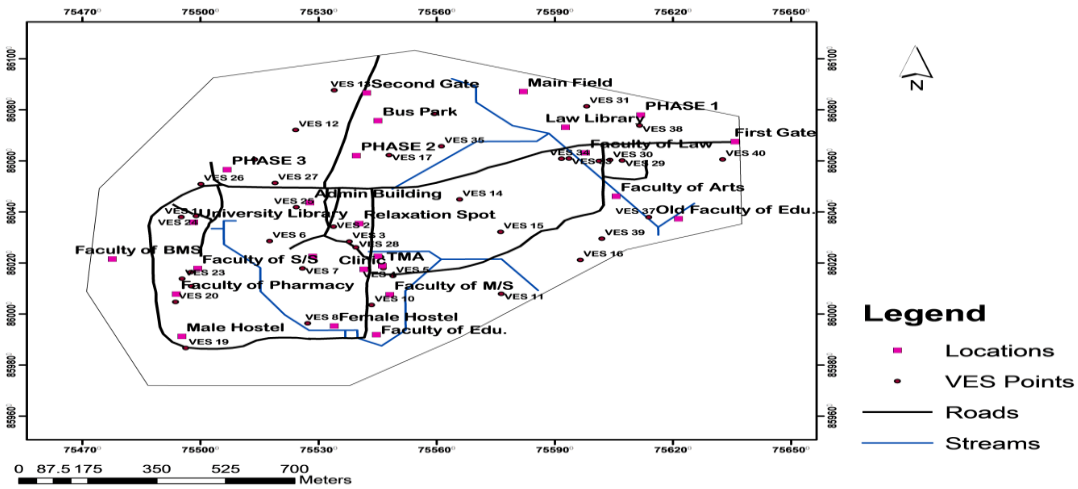

Figure 3: Data acquisition map indicating VES locations in the study area

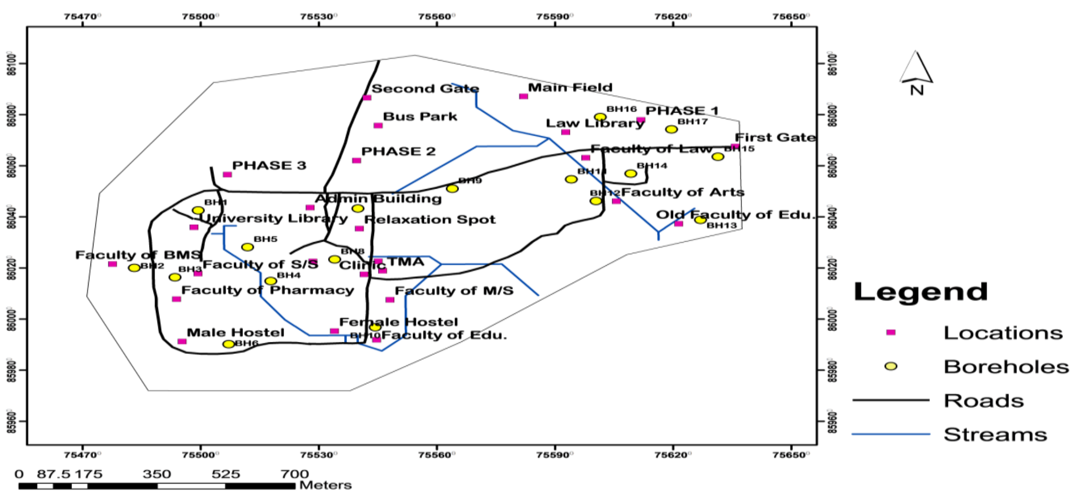

Figure 4: Map of the study area showing borehole location

RESULTS AND DISCUSSION

Multi-criteria decision analysis (MCDA) in the context of analytic hierarchy process (AHP) was employed in this research to develop "AHBD" model. Saaty (1980) proposed MCDA (AHP) and it was used to impel and attribute fitting weights to the established factors [depth to Aquifer (A), Hydraulic conductivity (H) and Bedrock relief (B)]. Procedures below were followed for the assessment of aquifer vulnerability within this region:

(a) Selection of depth to Aquifer (A), Hydraulic conductivity (H), Bedrock relief and lineament Density (D) as the parameters influencing groundwater vulnerability in the region.

(b) Comparison of two selected parameters at the same time,

(c) Matrix construction for (b) above,

(d) Relative weights determination for the parameters,

(e) Examination of the pairwise matrix consistency,

(f) Grouping and evaluation of the parameters,

(g) Assessment of the aquifer vulnerability index (AVI),

(h) Development of aquifer vulnerability conceptual model ("AHBD")

(i) Validation of the "AHBD" model generated in (h) above

Depth to Aquifer Map (A)

Layers overlying the aquifer at each of the VES stations (overburden material) are computed for the depth to aquifer map and it varies from 0.6 to 1.4 m (Figure 5). The depth to aquifer of the study can be classified as thin (administrative building), moderate and thick depth around male hostel, Faculty of Arts, Law and former Faculty of Education). Aquifers within the areas of thin depth are prone to contamination. The time taken for contaminant to penetrate from the surface to the aquifer of considerably thick depth will be slower than that of the thin layer (Olaseeni et al., 2020)

Hydraulic Conductivity Map (H)

Hydraulic conductivity is the ease at which fluid pass through a porous media (Olaseeni *et al.*, 2020)**.** The hydraulic conductivity of the region varies from 0.06 to 1.70 m/day (Figure 6) and can be classified as moderate to low except around the university library. Aquifers at high hydraulic conductivity area can be easily contaminated.

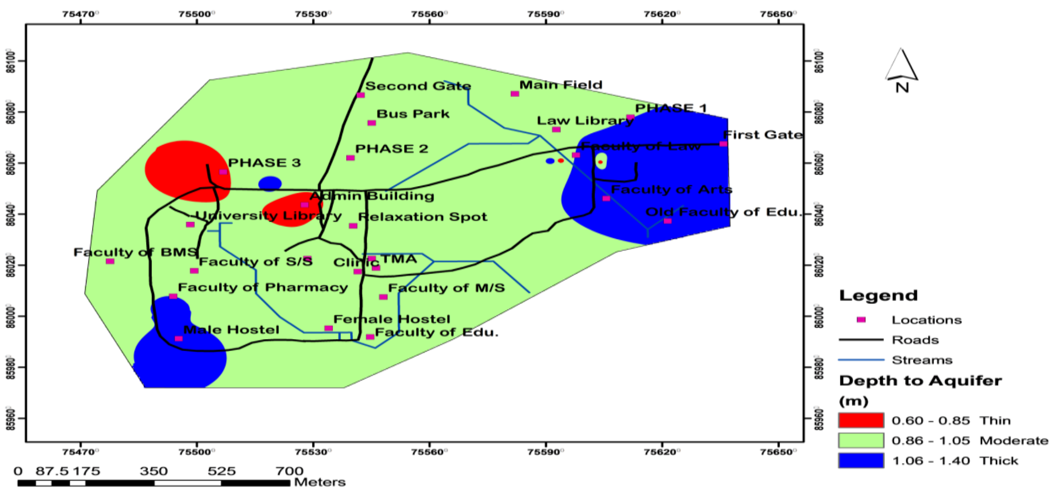

Figure 5: Depth to aquifer map of the study area

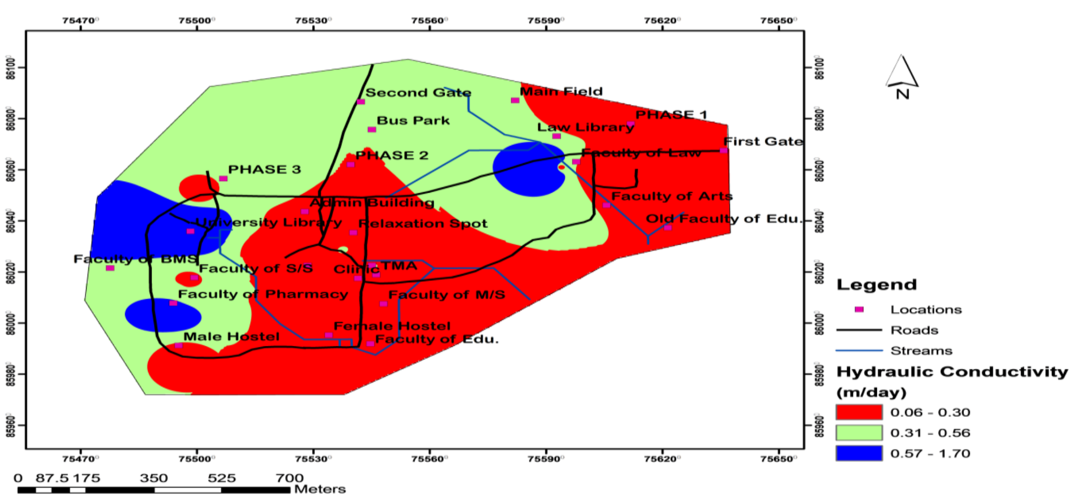

Figure 6: Map of hydraulic conductivity in the study area

Map of Bedrock Relief (B)

The bedrock relief map (Figure 7) shows an eastward subsurface gradient with the maximum bedrock relief in the western portion of the area. The bedrock relief map varies from 465 m to 539 m and can be classified into low relief (University Library), moderate relief (Faculty of Art, Former Faculty of Education, School Gate, male and female hostel) while other portions are of high bedrock relief.

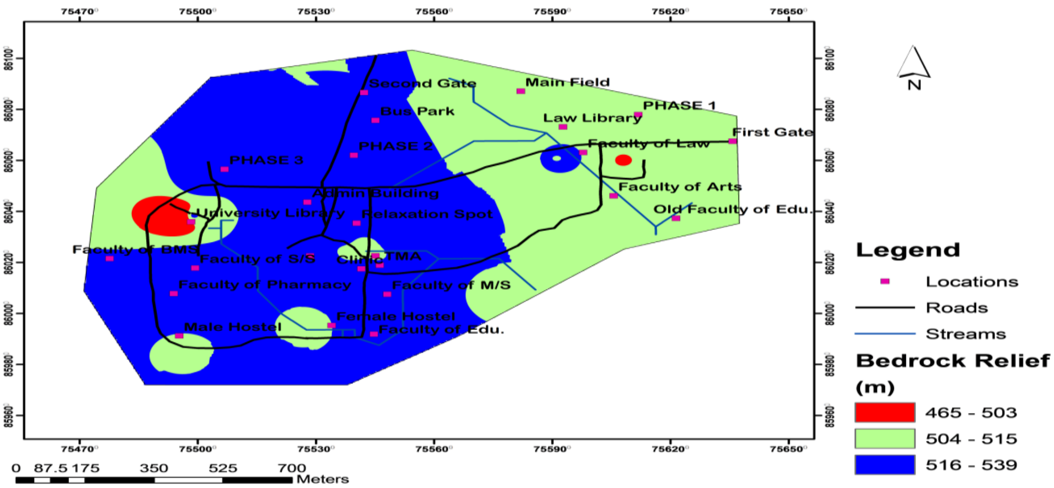

Figure 7: Bedrock relief map of the study are

Lineament and lineament density maps (D)

Landsat 8 Lineaments (Figure 8) and aeromagnetic lineaments (Figures 9 and 10) were superimposed and lineaments intercept were identified on the composite lineament map (Figure 11). It was later explored in generating lineament density (Figure 12) that can modify the aquifer vulnerability of the region. The major orientations of extracted lineaments are in NE-SW directions as shown on the rose diagram.

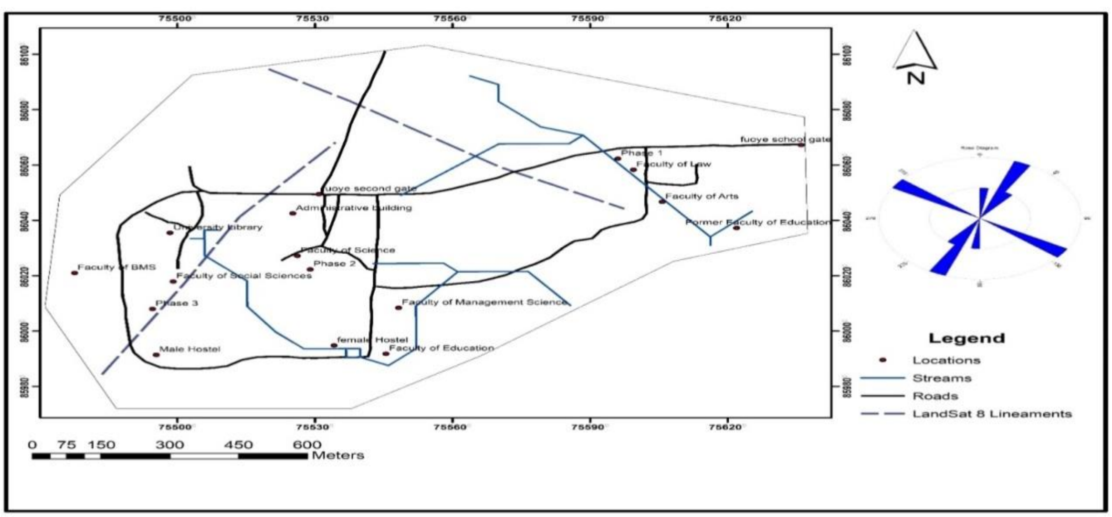

Figure 8: Landsat 8 Lineaments Map and Rose Diagram showing the Orientation of Lineaments in the Study Area.

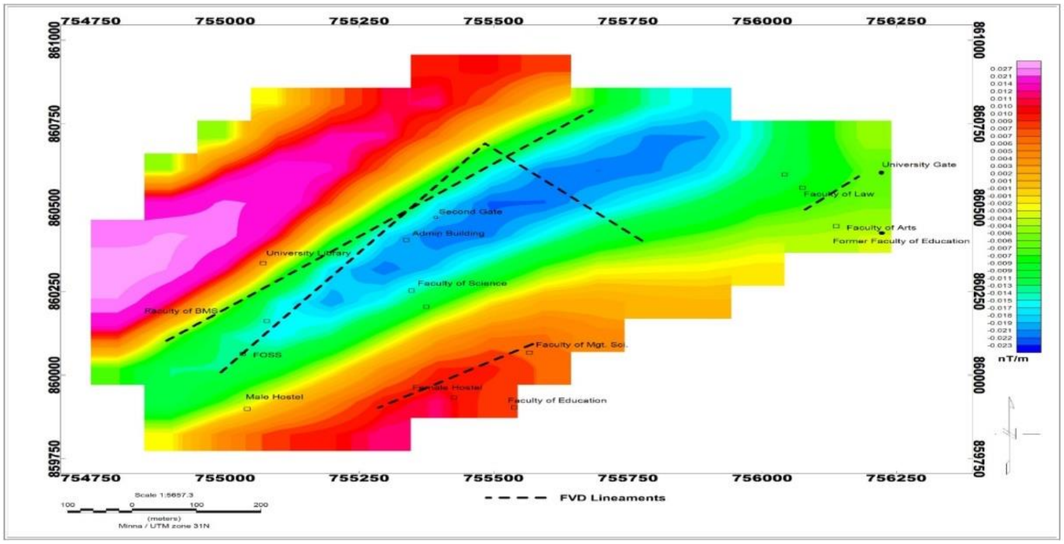

Figure 9: The study area's lineament concentrations are depicted on the first vertical derivative map (aeromagnetic derivative).

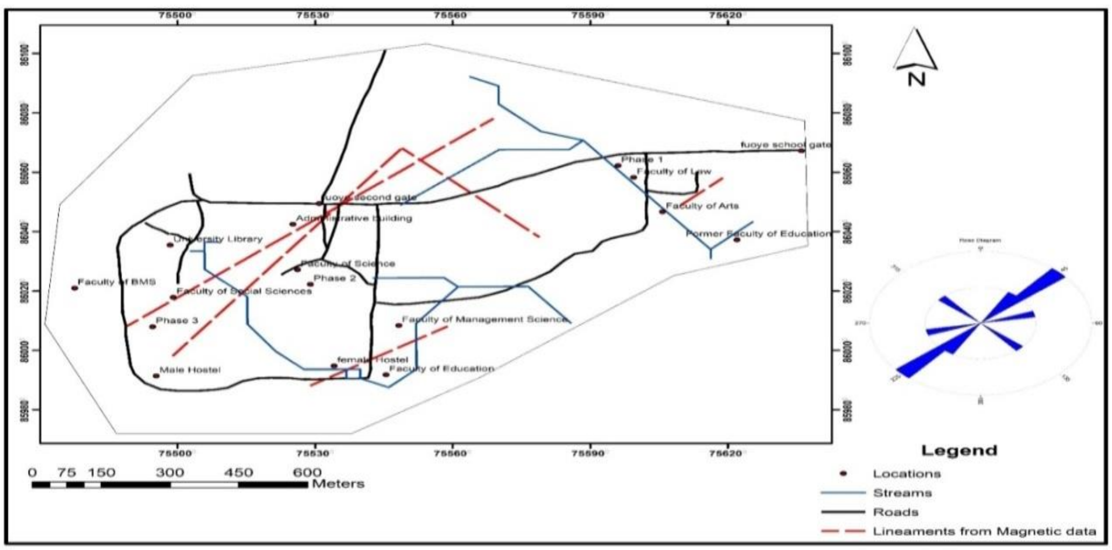

Figure 10: Lineament map from Aeromag of the study area

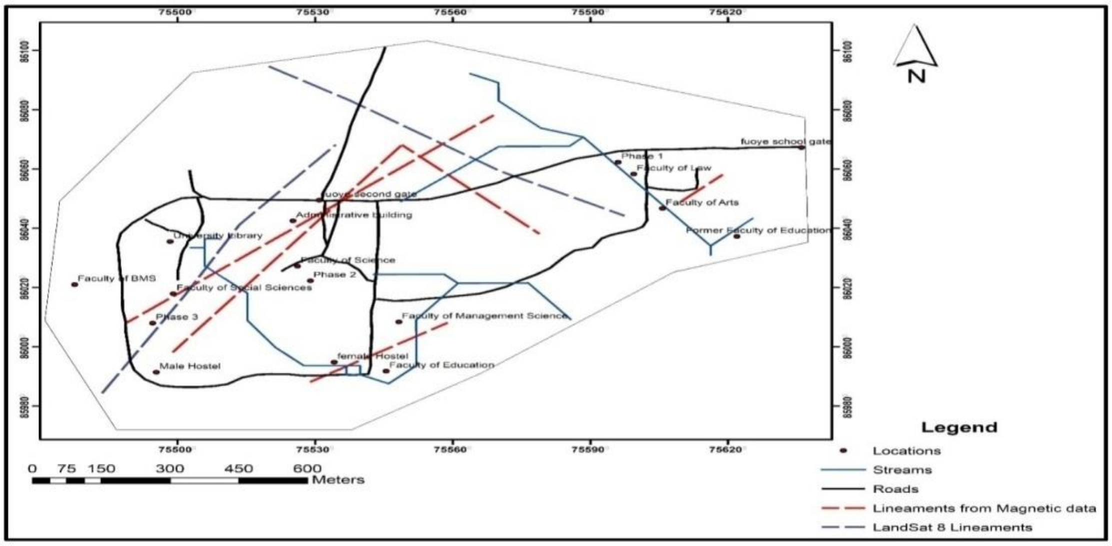

Figure 11: Composite Lineament Map of the Study Area

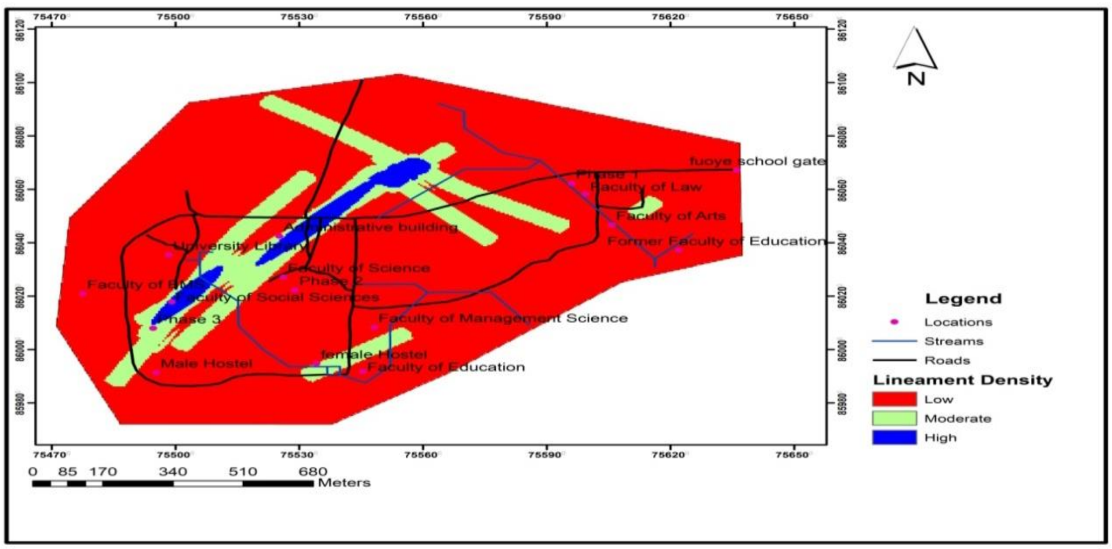

Figure 12: Lineament Density Map of the Study Area.

Consistency of pairwise matrix

Four parameters [depth to Aquifer (A), Hydraulic conductivity (H), Bedrock relief (B) and lineament Density (D)] selected for aquifer vulnerability were considered for matrix construction and weights were allocated to them accordingly. The results are presented in Tables 1 and 2 (Saaty, 1980). Consistencies are performed to ensure the dependability of the weights assigned. The vector sum and the weights are computed and showed in Table 3. The result for random consistency examination is presented in Table 4

Table 1: Matrix construction table for the aquifer vulnerability indices (Saaty, 1980)

Parameters	Vector sum× Assigned Weights	**λ max**
Da	1.73 (0.5436)	0.9404
Hc	4.66(0.2442)	1.1380
Br	9.33(0.1359)	1.2680
Ld	12(0.0763)	0.9156
Sum		4.2620

	Da	Hc	Br	Ld
Da	1	3	5	5
Hc	1/3	1	3	3
Br	1/5	1/3	1	3
Ld	1/5	1/3	1/3	1
SUM	1.73	4.66	9.33	12

Table 2: Relative weights determination for the aquifer vulnerability indices

	Da	Hc	Br	Ld	Weight
Da	0.5780	0.6438	0.5359	0.4166	0.5436
Hc	0.1908	0.2146	0.3215	0.2500	0.2442
Br	0.1156	0.0708	0.1072	0.2500	0.1359
Ld	0.1156	0.0708	0.0354	0.0833	0.0763
Sum	1	1	1	1	1

Table 4: Random index (RI) table for the examination of pairwise matrix consistency

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.9	1.12	1.32	1.41	1.45	1.45	1.49

The consistency interval (CI) is estimated using Eq. (1):

$$CI = \frac{(\lambda max - n)}{(n-1)},\ CI = \frac{(4.2620-4)}{(4-1)} = 0.0873 \quad (1)$$

$$CR = \frac{CI}{RI},\ CR = \frac{0.0873}{0.9} = 0.097 = 9.7\%$$

Consistency Ratio is 9.7%, which is less than 10% Recommended.

Since 9.7% < 10%, suggesting that weights of 0.5436, 0.2442, 0.1359 and 0.0763 from table 2 can be alloted to depth to aquifer, hydraulic conductivity, bedrock relief and lineament density respectively and were grouped into three classes. Evaluation of the aquifer vulnerability indices in the study area is showed in table

Table 5: Evaluation of the research area's aquifer vulnerability indices

AHBD Algorithm	Ranges (classes)	Pollution Potentiality for groundwater vulnerability	Rating (R)	Normalized Rating (NR)	Relative Weight	Normalized Weight (NW)
Depth to Aquifer (A)	0.60-0.85	High	3	0.46		
	0.86-1.05	Moderate	2	0.34	4	0.54
	1.06-1.40	Low	1	0.20		
Hydraulic Conductivity (H)	0.06-0.30	Low	1	0.20		
	0.31-0.56	Moderate	2	0.34	3	0.24
	0.59-1.70	High	3	0.46		
Bedrock Relief (B)	465-503	High	3	0.46		
	504-515	Moderate	2	0.34	2	0.14
	516-539	Low	1	0.20		
Lineament Density (D)	0-120	Low	3	0.20		
	121-250	Moderate	2	0.34	1	0.08
	251-400	High	1	0.46		

Aquifer vulnerability map ("AHBD" model)

The developed model (Figure 13) reveals the ease at which the aquifers in the region are exposed to contamination. Eastern and southern parts of the study area are considered to make up low to moderate aquifer vulnerability to contamination zones while northern part reveal high grade of aquifer vulnerability to contaminations. Northern part aquifers (university library and administrative building) are categorise as high risk areas because of thin to moderate depth to aquifer, high hydraulic conductivity, low to moderate bedrock relief and high lineament density in these areas. Human activities should be controlled around high vulnerability zones.

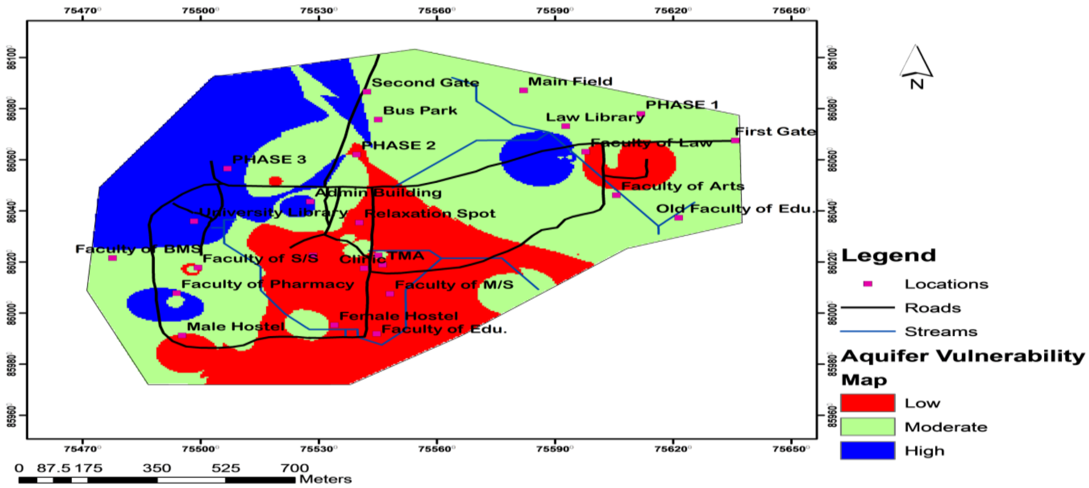

Figure 13: Aquifer Vulnerability Map ("AHBD" model) of the Study Area

Validation of the model ("AHBD" model) using geochemical data

Seventeen (17) water samples were collected and analyzed from the study area and the geochemical results were compared with the 2020 report of the Nigerian Industrial Standard (NIS) and World Health Organization (WHO) for drinking water. Elemental compositions such as nitrate, calcium and magnesium above the threshold were observed for each of the samples. Magnesium levels ranged from 21 to 110.3 mg/l and were observed not to be polluted. Nitrate and Calcium elemental composition showed values lower than WHO values of Nitrate and Calcium for most of the samples. Thirteen (13) water samples (76%) were in perfect correlation with the conceptual "AHBD" model derived out of the 17 water samples analyzed, while four (26%) failed to be in agreement. 76% of agreement shows a relevant degree of accuracy of the "AHBD" model and also the dependability of the MCDA(AHP) approach.

5. Conclusion

Remote sensing, aeromagnetic and electrical resistivity results were used to assess aquifer vulnerability to contamination in a typical basement complex terrain. "AHBD" model was developed through multicriteria decision analysis. Four parameters (depth to aquifer, hydraulic conductivity, bedrock relief and lineament density were selected to influence the aquifer vulnerability in the area. Low vulnerable zones were noticed at the eastern and southern parts while northern parts (university library and administrative building) were identified with high vulnerable zones. 76% of agreement were obtained from water samples analysis using geochemical parameters to validate the "AHBD" model and also to discover relevant degree of accuracy and the dependability of the MCDA(AHP) approach used. Constructional activities such as soak away, lying of pipes and so on should be minimal or guided around high vulnerability zones.

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