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The Relationship Between Morpho-structural Features and Borehole Yield in Ilesha Schist Belt, Southwestern Nigeria: Results from Geophysical Studies

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Abstract: Aeromagnetic data and Landsat image, were assessed to establish a relationship between morphostructural feature and borehole yield of a sub-basin of Osun basin in the Northern part of Ilesha, southwestern Nigeria. Four morphostructural factors (Geomorphological unit, Slope, regional structure, and lineament) were considered. Geomorphological units were classified based on digital elevation model (DEM), Lineaments were identified and extracted using edge detection technique, slope were generated from the digital data derived from Landsat imagery, and the regional structure were extracted using magnetic data filtering and enhancement techniques processes. The results of morphostructural features shows five (5) various geomorphic units; (Denudation hill, linear ridge, pediment inselberg complex, pediment and moderately weathered Pediplain) and four (4) main structural trends (NE-SW, NW-SE, ENE-WSW and E-W directions). The relationship between the morphostructural factors and borehole yield were assessed using spatial global autocorrelation and spearman rank correlation. Moran's I global tests for dependence shows that geomorphological units, and regional structures were clustered given the z-scores of 2.46 and 1.99, p-values of 0.01 and 0.04, Moran's I index value of 0.08 and 0.06 respectively. Likewise, borehole yield, lineament and slope were dispersed given the z-scores of 0.89, -0.43 and -1.15, p-values of 0.38, 0.66 and 0.25, Moran's I index value of -0.06, -0.04 and -0.07 respectively. The Spearman's rank correlation for the four independent variables (Geomorphological unit, Slope, Fracture, and Lineament) are statistically significant to the observed borehole yield, with correlation coefficients of -0.332, 0.137, -0.031, 0.200 respectively. The study concluded that slope and lineament are capable of favoring high borehole yield indicative of active surface recharge mechanism that is prominent in Schist belts and regional structures have little or no contribution to borehole yield in schist belts due to the influence of developed clayey filling resulting from the deep weathering processes.

Keywords: Morphostructural Factors, Lineament, Borehole Yield, Moran's Index

1. Introduction

Groundwater is an important natural resource for human well-being, and livelihood in most part of sub-Saharan Africa [1]. Groundwater occurs in various types of rocks. It can be found in the saturation zone, which is found in pore spaces between mineral grains or cracks in rock masses [2]. It is often considered as the cheapest water supplies because it requires little or no treatment. Abstraction of groundwater from shallow aquifers was initially limited, owing to the small number of wells dug and the use of less energized water-lifting pumps. A constant increase in the number of wells and high-energized pumps capable of much higher yield had resulted in a decline in the water table, causing shallow wells to dry up. Globally, the United Nations (UN) estimates that approximately 1.8 billion people will live in countries with absolute water scarcity by 2025 [3]. In Nigeria, large proportion of the population rely on groundwater as a major source of water consumption. This resource is considered the personal property of the landholders, with each holder drilling indiscriminate boreholes without regard for management. As a result, many shallow wells have dried up, contributing to the problem of water scarcity. In Ilesha and its environs, Akinwumiju [4] reported the problem of water shortage / scarcity. He estimated that only 32.7% of the household could meet their water demand and the coverage will reduce to 27.2% in the decade 2021 – 2030. These problems were attributed to many wells no longer being productive as they are dried up.

Addressing the issue of water scarcity and overexploitation is a complex phenomenon that can only be resolved through effective groundwater management. One of the major prerequisites for effective groundwater management is a thorough understanding of the aquifer system. A practical solution to the problem is to assess groundwater resources in the area using yield data prior to well planning, design, and operation. However, the limited amount of available groundwater yield data is insufficient to develop and support efficient systematic groundwater resource management.

Application of geophysics and remote sensing with GIS for hydrogeological evaluation has been proved to be efficient [5-15]. Integration of these methods gives more reliable results in groundwater exploration and reduce the risk of drilling of dry or low output boreholes [16-18]. Also, many researchers have utilized statistical methods and numerical modelling to assess groundwater potential with a view to predicting well yield [19-24, 9], and [14]. In most cases, the models prediction were based on arbitrary selection of factors without considering the prevailing factors influencing the yield of groundwater resources at the watershed scale and the results of such predictions could be misleading.

The groundwater yield of an aquifer in crystalline rocks is affected by various factors including lithology, geomorphology, tectonics, and climate conditions [25]. All these factors are responsible for spatial-temporal variations that were observed in the results of groundwater yield of an area. For example, the influence of rock types has been regarded as one of the factors controlling groundwater yield [12, 25]. Aquifers in basement complex terrain are localized and confined to weathered/fractured zones [26]. Studies have shown that the geometry and hydrodynamic properties of aquifers in basement complex varies due to the varying degree of weathering of the parent rock. The clayey nature of the saprolite associated with majority of the rocks were responsible for the aquifer's low yield. The clayey materials are impermeable material with poorly connected pores. Furthermore, it is assumed that individual rock types with similar geological histories and responses to brittle deformation have similar hydrogeological properties at the watershed scale [27]. These are in most cases the obvious factors that give plausible explanation to the variations in borehole yields [28]. However, researches affirm that even though the influence of the parent rock exists, its effects can be supplanted by the presence of a set of interconnected and open discontinuities [29, 12]. In addition, the influence of topography on groundwater yield has been studied by several authors [30-32]. Results reveal that wells located in valleys and flat areas show generally higher yields compared to wells located on slopes and hilltops. According to Yeh et al. [33], and Akinwumiju et al. [32], plain areas can be more productive due to the presence of thicker superficial coverings that allow good conditions for recharge. Some authors consider topography to be a minor feature, stating that its influence on well productivity is less significant due to observed variations related to structures and rock types. Furthermore, analysis of the lineaments and geological structures (such as tectonic faults, fracture zones and dykes) constitutes the backbone of borehole siting, as major discontinuities and their intersections are often assumed to be strong indicators of a groundwater resource [34, 10, 13]. Tessema et al. [35] accounted that highly fractured zones, extending over dozens of kilometres, might harbour great hydraulic conductors. However, others point out that such structures do not necessarily give impressive results in terms of well yield [36]. The influence of the filling of the impermeable materials represents the main factor in this case, since large fractured zones tend to develop clayey filling resulting from the weathering of fragmented material. Therefore, it can be deduced that the factors that actually influence the productivity of wells in crystalline rocks often vary with respect to the specific characteristics of the area. Thus, investigating existence of relationship between morphostructural features and borehole yield over a given area is very important. In addition, many of the prevailing factors influencing the groundwater yield at medium and regional scale lies are highly variable and difficult to characterize over a given area. Thus, it is a spatial problem that requires geospatial input, processing, analysis and solution from many experts.

2. Geography and Geology of the Study Area

The study area is a sub-basin of Osun basin in the northern part of Ilesha, southwestern Nigeria. It is defined by Latitudes 7° 35'N – 7° 50'N and Longitudes 4° 37'E – 4° 52'E (Figure 1). It has a tropical climatic condition with dry and rainy seasons. The dry season lasts from November to February, and the wet season lasts from March to late October. It experiences an annual average rainfall of about 1500 mm and temperatures range between (21.4 and 31.1) °C [37]. The study area is drained by the Osun and Mokuro River. Their tributaries drain the entire study area. The ridges in the area constitute the source of the tributaries with the orientation of flow (predominantly N-S and NE-SW directions) suggesting structurally-controlled courses. Awoyemi [38] suggests that the drainage patterns are trellis and dendritic.

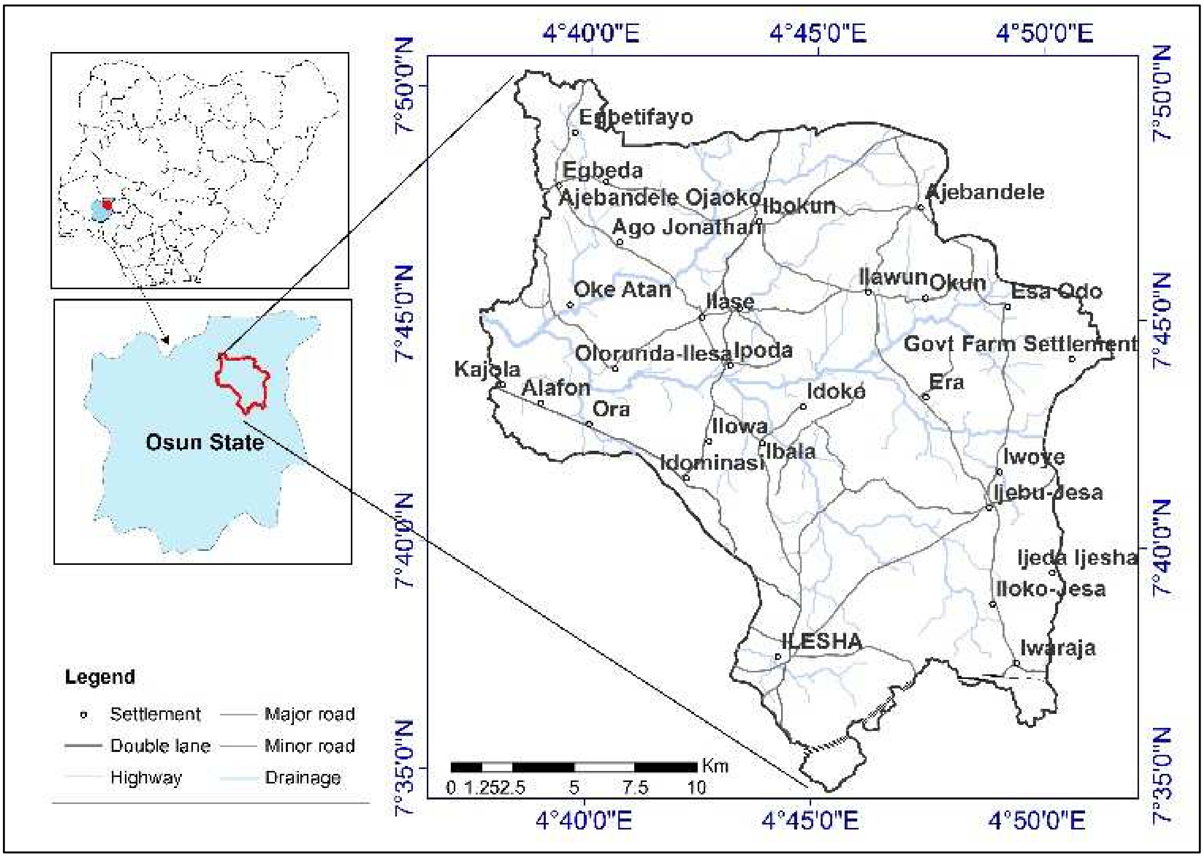


Figure 1. *Base map of the study area. (Modify after Topographic map of Ilesha NE, NW, SE and SW Sht 243).*

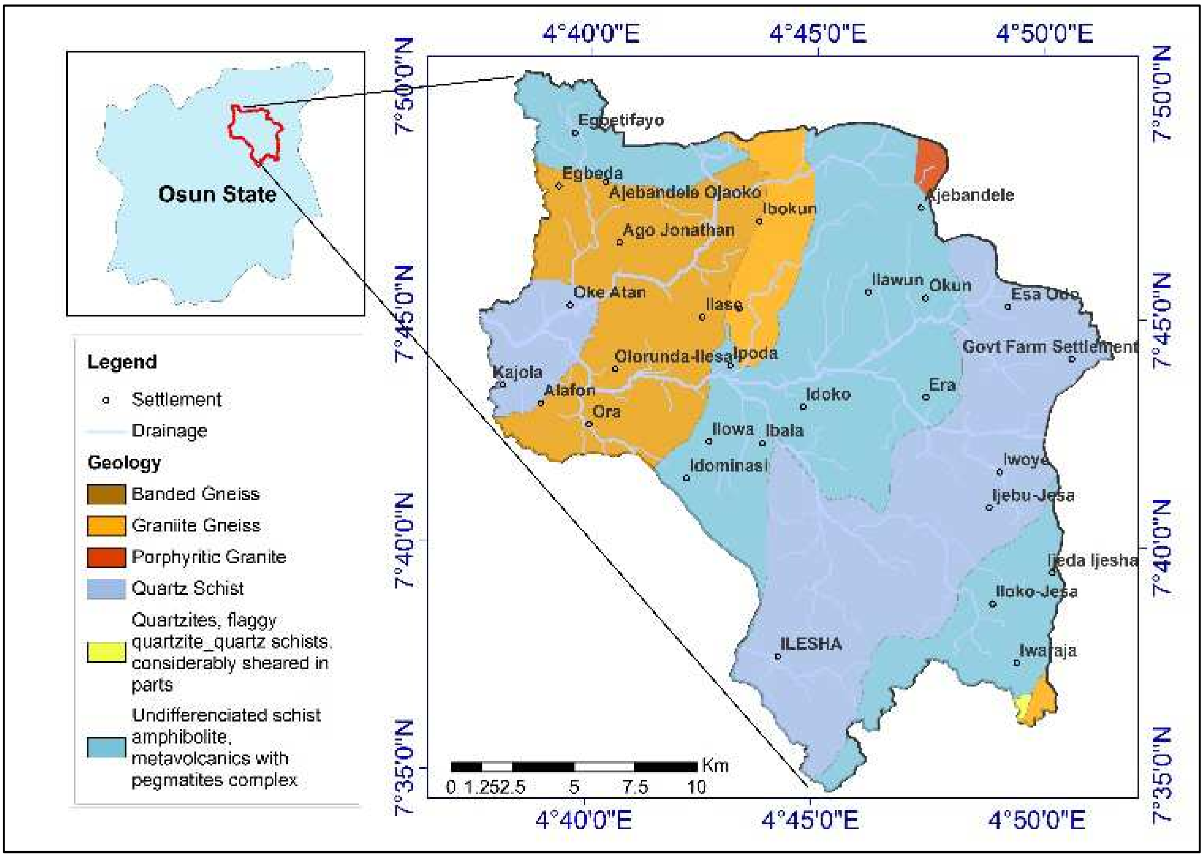


Figure 2. *Geological map of the study area (Modify after Nigerian Geological Survey Agency 2006).*

The study area is a part of the Ilesha schist belt (Figure 2). The Ilesha Schist belt is part of the Nigeria Basement complex, which is underlain by late Precambrian basement rocks. The rock evolution is related to late Proterozoic rocks and bears the imprints of the Liberian (2700+ 200Ma) and Eburnean (2000+200Ma) orogenic events. [39]. The Ilesha Schist belt has been shown to consist of two structural units with contrasting lithology separated by the NNE-trending Ifewara shear zone in the western part and Iwaraja shear zone in the east [40-42]. The western unit is distinguished by narrow, sediment-dominated N-S trending, low-grade schist belts in a migmatite gneiss basement intruded by Pan-African granitic plutons. [43]. The unit is made up of amphibolite, amphibolite schist, and pellitic schist, all of which are closely related to trondhjemitic granite, gneiss, and pegmatite.

The Eastern unit is dominated by quartzite, which is found alongside quartz schist, quartzo-feldspathic gneiss, and minor iron-rich schists [44]. The observed relationship between basement complex rocks suggests that the rocks were affected by polycyclic episodes of deformation and metamorphism during the multiple stage Pan-African orogeny. [45, 46]. This has resulted into distinct topographic features and various structural features (folding, refolding, fracturing and shearing) found in the area [44, 47, 41, 48]. On this premise, this study intends to investigate the influence of morphostructural features on groundwater yield distribution in the area using integrated geophysical and geomorphologic methods. Also, information from fieldwork established that the area suffered from seasonal water scarcity as a results of well been dry up during the dry seasons or well having extremely low yields during the dry season.

3. Material and Methods

Datasets utilized for the studies were remote sensing, borehole records, vertical electrical sounding data, and aeromagnetic data.

3.1. Borehole Records

The borehole records of the study area were acquired from Osun State Rural Water and Environmental Sanitation Agency (RUWESA). It is important to note that these boreholes are not randomly distributed but were limited to the proximity of rural villages (Figure 3). The borehole records consist of borehole coordinates, static water level, borehole depths, borehole yield, and borehole lithology. The pumping tests were single-well tests, primarily to recommend sustainable abstraction rates for rural water-supply schemes.

3.2. Lineaments and Geomorphologic Features

The remote sensing data utilized were Landsat 7 ETM+ and Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) data. Landsat 7 ETM+ scenes of paths/rows: 190/055 with spatial resolution of 30 m and (SRTM) digital elevation model (DEM) covering the study area were acquired from (http://earthexplorer.usgs.gov/). The data were processed in order to clearly identify the lineaments and geomorphological units associated with the area. Histogram Equalization and Shaded Relief were conducted on the SRTM DEM data using ArcGIS spatial analyst tools.

When the histogram equalization technique was used, pixel values in the DEM's lower range became visible, and subtle differences were observed. However, using a shaded relief cartographic technique, these data were optimized for comparison with other data. This resulted in a sun-angle shaded representation of the DEM data, which could be combined with a variety of other data for visual and statistical analysis. The shaded relief map allowed geomorphic changes in the environment to become more apparent based on elevation of the study area. These techniques highlighted different geomorphological features within the study area.

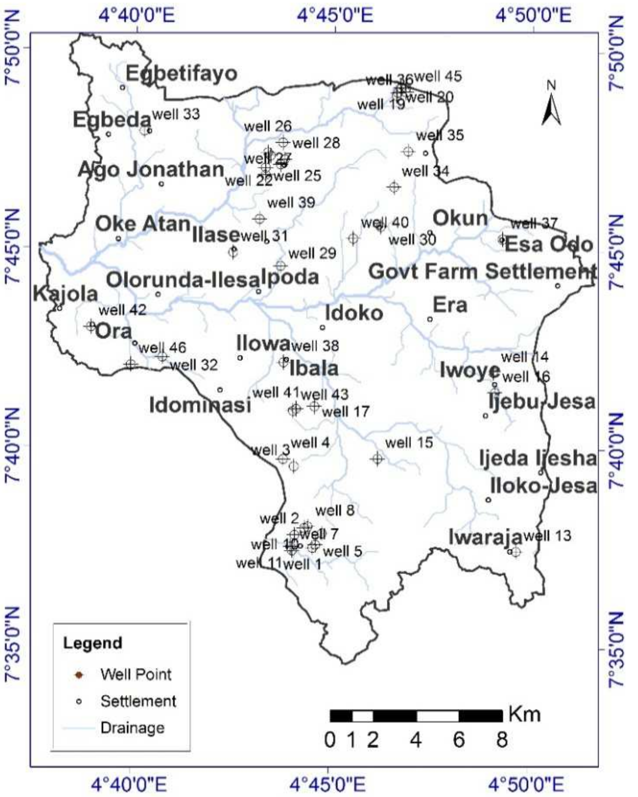


Figure 3. Borehole distribution map of the study area (Osun State Rural Water and Environmental Sanitation Agency Records (RUWESA).

The Landsat 7 ETM+ bands (1, 2, 3, 4, 5, and 7) were mosaicked and area of interest (study area) were clipped. Principal Component Analysis (PCA) was used on the composite band to identify the band(s) with high loading factors i.e. the band that is contributing more to that component. Directional filtering and edge enhancement were applied using LINE algorithm on PCI Geomatica 2015. The LINE Module used the canny edge detection technique which has been found to overcome most of the limitations associated with Hough transform and other methods of edge detection [49, 50]. These lineaments were identified and digitized to produce the lineament map. The directional analysis of the lineaments was prepared from the geometry of the lineaments using the azimuth of the prominent lineaments.

3.3. Fractures

Aeromagnetic data collected by Nigerian Geological Survey Agency was acquired and processed accordingly. This data was processed with a view to improving the magnetic response of lineaments and fractured bodies. Data filtering and enhancement techniques utilised include the use of upward continuation filter, Reduction-to-Earth-Magnetic-Equator, Residualisation, Tilt angle derivatives, and Total horizontal derivatives. To remove the effect of shallow noise and improve the magnetic signal, an upward continuation filter was used [51], followed by reduction-to-the-equator (RTE) which shifts the anomalies to lie directly over the causative body, and the regional field was removed from the main RTE fields in order to gives the resultant residual magnetic intensity anomaly maps of the area. The residual magnetic anomaly was subjected to different enhancement techniques such as tilt angle derivative (TDR), and total horizontal derivative (THD). The enhancements are applied for edge detection which is usually equivalent to fractures, faults, lithological boundaries, and crustal discontinuities which are very vital in groundwater exploration in the study area. Interpretation of the aeromagnetic data was carried out independently using magnetic processing procedures as established by several researchers [52, 53, 10]. Geological structures were extracted from the aeromagnetic data based on on-screen digitizing and the result was combined with similar features derived from Landsat 7 ETM image.

3.4. Spatial Analysis

Spatial relationship of morph-structural factors and borehole location is very important when assessing the influence of morph-structural factors to borehole yield. In view of this, spatial autocorrelation and Spearman rank correlation were utilized. Moran's I tests for global spatial autocorrelation for continuous data was used to assess the spatial dependence. This measure the correlations between the values of a random variable at a location and the same variables at "neighboring" locations [54]. It is based on cross-products of the deviations from the mean and is calculated for n observations on a variable x at locations i , j as:

$$I = \frac{n}{S_0} \frac{\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2},$$

where $\bar{x}$ is the mean of the x variable, w_{ij} are the elements of the weight matrix, and S_0 is the sum of the elements of the weight matrix: $S_0 = \sum_i \sum_j w_{ij}$.

Both morph-structural factors and borehole yield variables were subjected to Moran's I tests. The test evaluates whether the pattern expressed is clustered, dispersed, or random. The z-score and p-value measures statistical significance. When z-score or p-values indicates statistical significance, a positive Moran's I index value indicates tendency toward clustering, while a negative Moran's I index value indicates tendency toward dispersion as presented in table 1.

Table 1. *The Moran's I global spatial autocorrelation index value Scale.*

	Significant			**Random**	**Significant**		
Significant level (P-value)	0.01	0.05	0.10	0	0.10	0.05	0.01
Critical Level (Z-score)	< -2.58	-2.58 - -1.96	-1.96 - -1.65	-1.65 – 1.65	1.65 – 1.98	1.98 – 2.5	> 2.5
Pattern	Dispersed			Random	Clustered		

After the establishment of the spatial dependence of morph-structural factors and borehole yield across the study area, Spearman's rank correlation coefficient measure was found suitable to estimate the significance of each independent variable that required.

For Spearman's rank correlation coefficient, the squared difference is computed from ranks that are calculated separately for each variable and averaged for tied observations [55]. A positive correlation coefficient indicates a positive relationship between the two variables (the larger A, the larger B) while a negative correlation coefficients expresses a negative relationship (the larger A, the smaller B). A correlation coefficient of 0 indicates that no relationship between the variables exists at all. The correlation coefficient shows the strength of the relationship between the two input variables assuming that the coefficient was statistically significant at the two-tailed significance (i.e. α = 0.05) level, thus indicated by a prediction value (p-value) less than 0.05. We can verbally describe the strength of the correlation using the following guide for the absolute value as shown in Table 2:

Table 2. *The Spearman's rank correlation coefficient value scale.*

Significant level (P-value)	**0.00 – 0.19**	**0.20 – 0.39**	**0.40 – 0.59**	**0.60 – 0.79**	**0.80-1.0**
Significance Level (relationship)	very weak	weak	moderate	Strong	Very strong

In order to perform the spatial analysis, the borehole points were superimposed on the vectorized morph-structural maps. The values were extracted from the respective independent variable maps by considering the interpolation value of the variable at the well locations. These datasets were stored in a value attribute table (VAT). The attribute table of the point is exported to a database table where it can be accessed for analysis.

4. Results and Discussion

Structural and hydrogeomorphological units have been considered as good indicator on groundwater occurrence in hardrock terrain. Influence of structures on different rock types and landforms plays a critical role in groundwater distribution [56, 57].

4.1. Geomorphology and Drainage

Usually the underlying bedrock and structure will have a profound influence on the landform viz a viz the groundwater flow regime and groundwater storage of the area. A detailed geomorphological map of the study area has been prepared by using SRTM DEM and field observation data. The resulting geomorphologic map shows majorly five (5) various geomorphic units; Denudation hill, linear ridge, pediment inselberg complex, pediment and moderately weathered Pediplain (Figure 4). These units and their component were identified and mapped as shown in the table 3 below.

Table 3. *The geomorphological units and its characteristics in the study area.*

S/No.	Geomorphic Units or Landforms	Description / Characteristics
1	Dendudational Hill	High relief, moderate to steep slope. Barren, moderate to high hills.
2	Pediment Inselberg Complex	Pediment dotted with a number of inselbergs which cannot be separated and mapped as individual units
3	Linear Ridge	Linear to actuate hills showing definite trend lines.
4	Pediment	Gently undulating plains with moderate slope
5	Moderately Weathered Pediplain	Shallow depressed low relief area with good drainage networks.

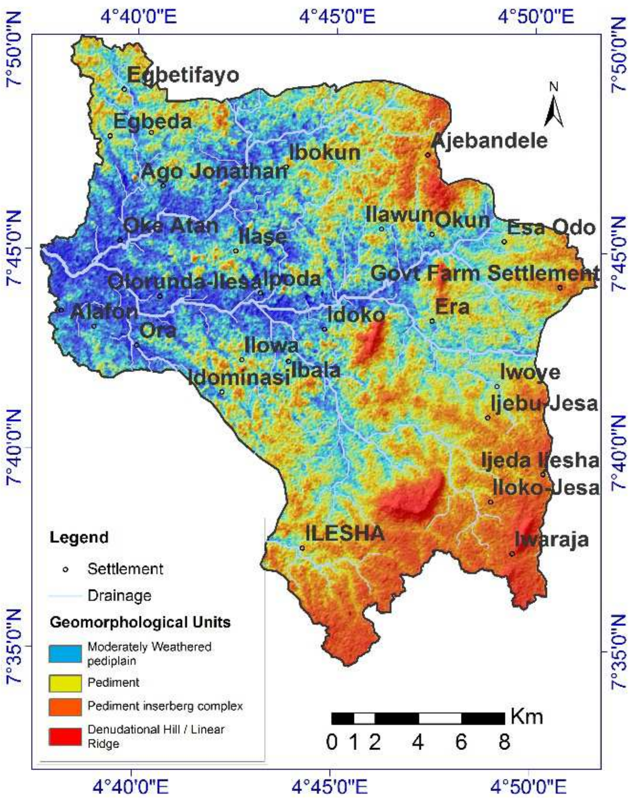


Figure 4. *Geomorphological map of the study area.*

The geomorphological units provide a panoramic view of the area's morphology. The units not only depict the surfaces of various landforms, but also plains with varying erosion surfaces and amplitudes of relief. The geomorphological units show a clustering of hilltops of three different levels, representing three different erosional surfaces. (Denudational hills, Pediment Inselberg Complex and Linear Ridge) in the study area at height groups of 368–388 m and 389–607 m. The geomorphological units were controlled by the lithology and structural features such as joints and fractures. The hill-tops landform acts as a high runoff zone and watershed boundary due to their steep slope relief. While the adjacent terrain consist of large undulation of the relatively flat, convex shape geomorphological units which represent two deeply weathered, shallow depressed surfaces (Pediments and Pediplain) in the study area at height groups of 327-368 m, and 224-327 m. The pediments have thin cover of soil, but its thickness may increase away from the pediment junction. The pediplain unit are generally characterized by high weathered mantle of bedrock with gentle to moderate slope. They are considered as the most suitable hydrogeomorphic class with less velocity of surface runoff and thus provides more chance of water accumulation.

4.2. Drainage

The system of the drainage is largely dendritic typical of structurally-controlled drainage along the sheared zone of metamorphic rock (Figure 4). The drainage system that develops in a given area is entirely determined by the slope, bedrock attitude coupled with regional and local fracture patterns. The study area is well drained. The drainage density is an inverse function of permeability. Areas of low drainage density are indicative of areas with a relatively good groundwater infiltration, which allows for more water accumulation.

4.3. Structural Features

Lineaments are the surface manifestation of structurally controlled features such as faults, dykes, and joints that can be traced using enhanced magnetic and satellite imagery. Lineament analysis thus provides important clues about features that are responsible for groundwater infiltration and storage. Lineament were delineated by using the combination of bands from the visible, mid-infrared and shortwave infrared bands of Landsat 7 ETM. Principal components analysis (PC1 to PC6) results are presented in tables 4 and 5. Table 4 shows the eigenvector which depicts the factor score that the six spectral bands contributed to the six principal components. Higher values indicate a greater factor loading. This is the same regardless of sign, i.e. a high negative value also indicates a high factor loading. From the score on the table, the first three components made up 97.3% of the available variance and carry most of the spectral information in the total data set available for analysis. Images resulting from RGB combination of PCA (PC 1, 2, 3) were used as reference points to digitize the lineaments in the area of study. The distribution of the lineaments in the study area concentrated in the central and southern part, with few lineaments in the northern part of the study area (Figure 5).

Table 4. *Eigenvectors of the principal component analysis results.*

	Eigenvectors					
	P1	P2	P3	P4	P5	P6
Band 1	0.09250	-0.13000	0.21991	0.20970	0.89800	-0.27533
Band 2	0.14249	-0.13982	0.29437	0.10624	0.14918	0.91649
Band 3	0.32924	-0.44339	0.55766	0.37731	-0.40721	-0.27540
Band 4	-0.07034	0.58988	0.70858	-0.37172	-0.01877	-0.08051
Band 5	0.62095	0.60578	-0.20451	0.45241	-0.02765	0.01362
Band 6	0.68718	-0.22809	-0.10048	-0.67789	0.06636	-0.04158

Table 5. *Eigenvalues of principal component analysis results.*

Components	1	2	3	4	5	6
Value	174.41270	10.03389	5.54644	2.40838	1.75352	1.08026
Eigenvalue (%)	89.33	5.13	2.84	1.23	0.89	0.55

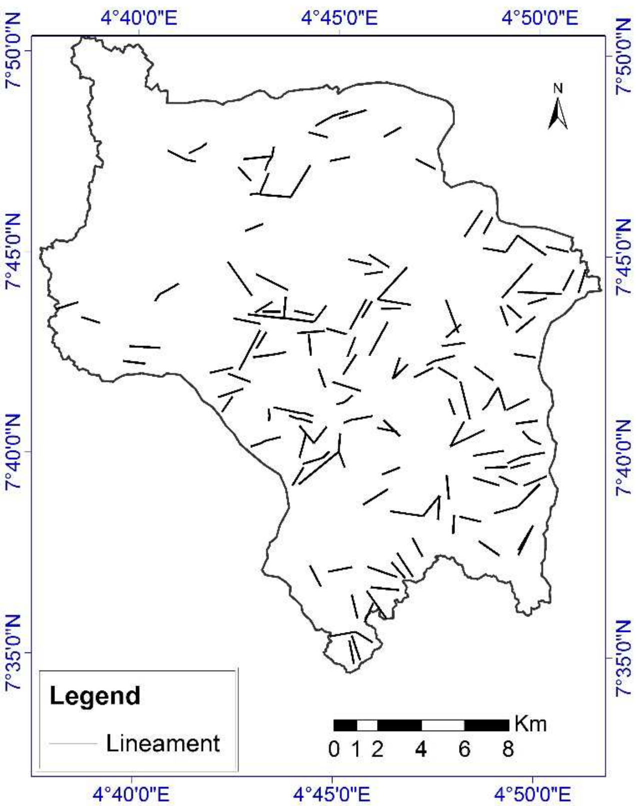


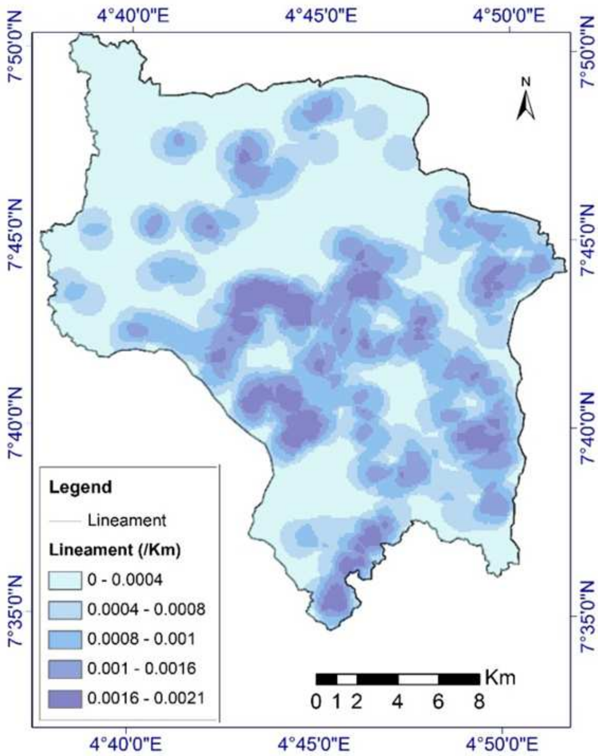
Figure 5. *Lineament map of the study area showing lineament features.*

The distribution of the lineaments as shown in the lineament density map expressed the brittle nature of various rocks in the study area (Figure 6a). The results of lineament analysis give us a proper interpretation of the main structural trends thus suggesting that the area is profoundly affected by several structural trends NE-SW, NW-SE, ENE-WSW and E-W directions as shown in the azimuths of the lineament expressed by the rose diagram (Figure 6b). These trending directions agrees with the polycyclic tectonic history that had been reported in the literature of the study area. Lineament reveals regional tectonic trends, faulting pattern, structural displacement and fracture zones. These are believed to favour groundwater occurrence and yield in the area.

The aeromagnetic data analysis focused on determining and characterizing the magnetic anomaly related to geological structures. The total magnetic intensity (TMI) map of the study area is presented as a colour-shaded relief map (Figure 7a). The total magnetic intensity varies from -166 to 147.2 nT. High amplitude regions were observed in the northern and central parts of the map and low amplitude regions characterize the southern sections of the map. The low amplitude zones display a NNE-SSW trend. The total magnetic intensity (TMI) map shows an acute variation in the magnetic intensity indicating variations in either lithology or basement topography.

Edge enhancement techniques were utilized to delineate magnetic structures. For this study edge enhancement techniques utilized were Total Horizontal Derivative (THD) and Tilt Angle Derivative (TDR). Total Horizontal Derivatives are commonly used to improve the details in magnetic data and detect the edges of magnetized structures. Similarly, the Tilt Angle derivative reveals the presence of magnetic lineaments by utilizing the automatic-gain-control (AGC) function, which tends to equalize the response from both weak and strong anomalies. These filters were used to identify magnetic source structures such as fractures, faults, contacts, and edges or boundaries. Delineation of these structures are important to groundwater prospecting in the study area.

On the THD map, peak (maxima) anomalies are observed over contacts and prominent geologic structures (such as fractures or faults) in the study area (figure 7b). These contacts and structures were identified and presented as continuous and discontinuous line features on the THD map respectively. These structures aligned in approximately N-S, NE-SW and W-E directions. They are prominent in the eastern, northern and central parts of the study area. These delineated contacts moderately coincide with the existing geological contacts earlier mapped in the area of study. The delineated contact zones and structures probably favours groundwater flow and accumulation in the area. Also, on the TDR map, the amplitude of the tilt angle is positive over the magnetic sources, crosses through zero at or near the edge of the source (figure 7c). The amplitudes of the tilt ranges from -1.3 to 1.3 nT^2/m^2. The contact and structures were presented as continuous and discontinuous line features on the TDR map. Some of these contacts and structures coincides with delineated structures on the THD map. The delineated magnetic structures trends approximately in the N-S, NE-SW and W-E directions. These magnetic structures are in alignment with the tectonic metamorphic deformation trend reported by previous literatures. The delineated contact zones and structures are presumed to favour groundwater flow and accumulation in the area.



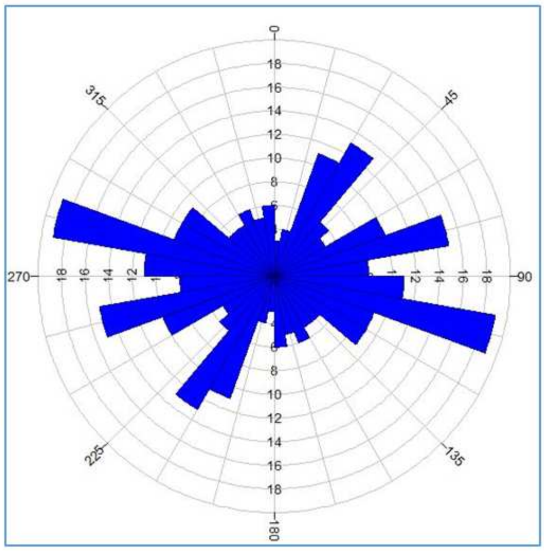


Figure 6. (a) Lineament density map of the study area and (b) Rose diagram showing the azimuth of the lineaments.

Structural features across the area were overlayed on the geomorphological unit to establish the spatial relationship of the morphostructural features of the study area. It is observed that the underlying bedrock and structure have a profound influence on the landform, viz a viz the drainage distribution of the study area.

4.4. Spatial Analysis Result

Integration of the geomorphostructural factors through weighting(s) and index overlay approach have been utilised to delineate potential recharge zones [1]. However the result was subjective based on expert opinion to assign weight. Therefore, spatial analysis was performed to establish the significance of different factors utilised.

The Moran's I tests results conducted for borehole yield values show that the borehole yield distribution pattern across the study area is random given the z-score of -0.89, p-values of 0.38 and Moran's I index value of -0.06. This depict the random borehole yield within a neighboring location across the study area. It affirms the observation that higher yield boreholes co-locate with some low yield boreholes. This describes the heterogeneous media of the groundwater system of the study area. Moran's I test were also conducted for the morpho-structural factors considered in the study area (lineament, slope, geomorphology, and fractures). The results were presented in table 6. For geomorphology and fracture, the results show a cluster distribution pattern given the z-scores of 2.46 and 1.99, p-values of 0.01 and 0.04, Moran's I index value of 0.08 and 0.06 respectively. These depicts the cluster nature of geomorphologic features within the neighbouring location and also indicate that the fracture zones are localised across the study area.

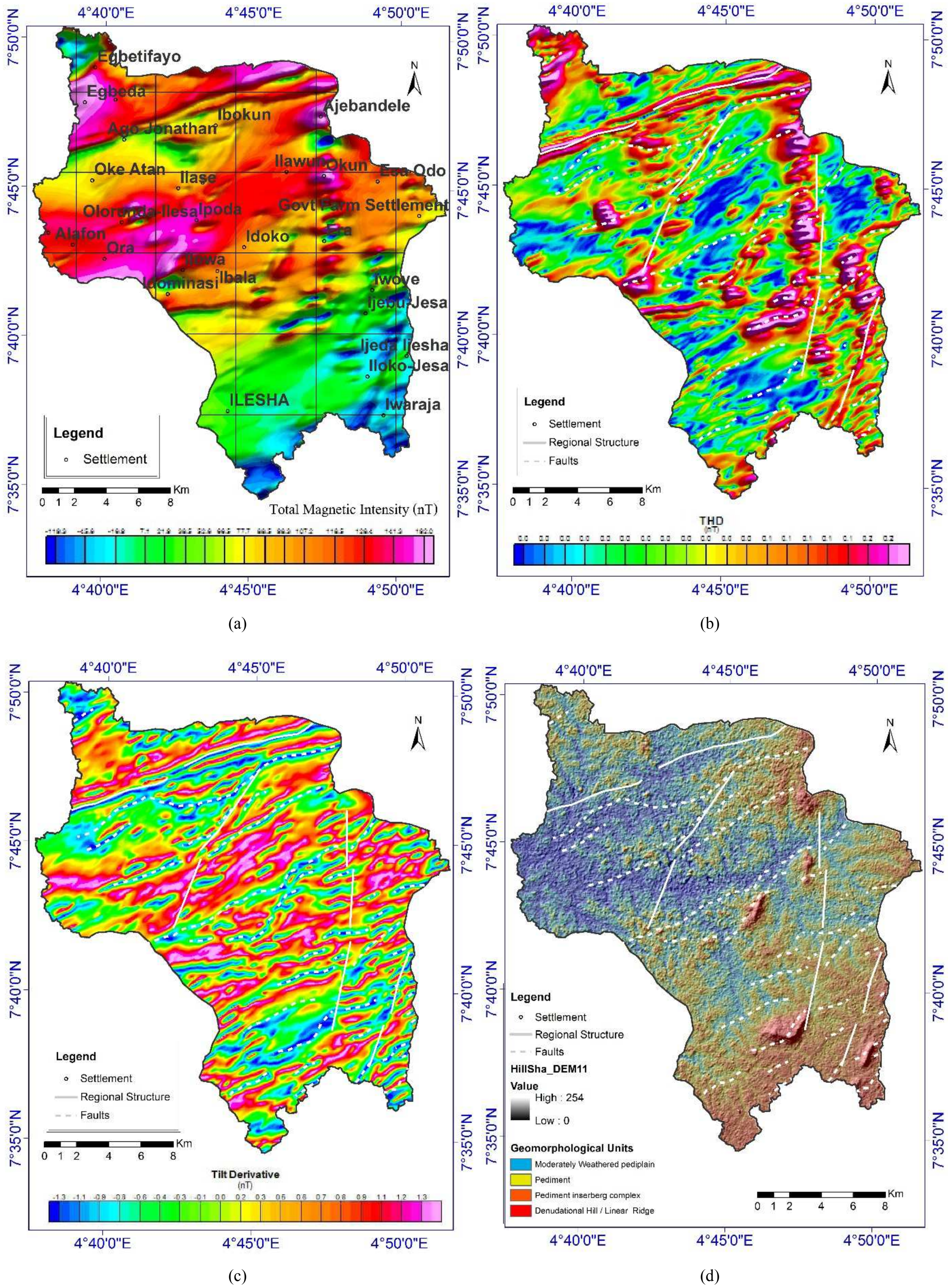


Figure 7. *(a) TMI map of the study area (b) THD map of the study area (c) TDR map of the study area and (d) Morphostructural map showing structural features characterizing each geomorphological units.*

Table 6. Moran's I tests for Spatial Autocorrelation.

	Z-score	P-value	Moran's I index	Variance
Borehole Yield	-0.89	0.38	-0.06	0.002
Geomorphology	2.46	0.01	0.08	0.002
Slope	-1.15	0.25	-0.07	0.002
Fracture	1.99	0.04	0.06	0.002
Lineament	-0.43	0.66	-0.04	0.002

However, lineament and slope show a disperse distribution pattern given the z-scores of -0.43 and -1.15, p-values of 0.66 and 0.25, Moran's I index value of -0.04 and -0.07 respectively. These indicate the random distribution pattern of lineament and slope associated with the well location within the neighboring location across the study area.

From these spatial analysis result, we can deduce that despite the location of borehole within same geomorphologic unit and localized fracture system in the study area, the observed borehole yield still varies. This variation in the borehole yield may be due to other factors that are not localized within a geomorphologic unit. The random distribution of slope and lineament may likely be related to the observed variations in borehole yields in the study area.

4.5. Bivariate Correlation

The result obtained from the Spearman's rank correlation for the four independent variables (Geomorphological unit, Slope, and Lineament) are statistically significant to the observed borehole yield, as presented in Table 7. The correlation coefficients are -0.332, 0.137, -0.031, 0.200 at the two-tailed significance (i.e. α = 0.05) level respectively.

Table 7. Spearman's Rho Correlations of Each Variable Utilized in the Study.

	Well yield	Geomorphic	Slope	structure	Lineament
Well yield	1.000				
Geomorphic	-0.332*	1.000			
Slope	0.137	0.097	1.000		
Structure	-0.031	0.112	-0.095	1.000	
Lineament	0.200	-0.307*	-0.031	0.035	1.000

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

The geomorphological units have very strong negative correlation with borehole yield with variable coefficient of 0.332 respectively. This implies that geomorphological units (denudation hill, linear ridge, pediment inselberg complex), of high elevation were associated with low borehole yield while geomorphological units (pediment and moderately weathered Pediplain) with low elevation were associated with high borehole yield. Regional structures have very weak negative correlation with borehole yield with variable coefficient of -0.031. This implies that the regional structures have little contribution to the borehole yield and thus low and high yield borehole co-located within the fractured zones. In contrary, Slope and lineament have strong positive correlation with borehole yield with variable correlation coefficients of 0.137 and 0.200 respectively. This implies that high slope and lineament were associated with high borehole yield. Although the random distribution pattern of slope and lineament reveal that high and low borehole yield co-locate in the study area.

5. Conclusion

Quantitative assessment of the relationship between Morphostructural features and Borehole yield serve as a useful guide for identification of groundwater exploration target with good yield in crystalline basement rock of the study area. A positive Moran's I index value of 0.08 suggest that geomorphology show a cluster distribution pattern with each geomorphological unit expressing same geomorphologic features within the neighbouring location. Also, the positive Moran's I index value of 0.06 for fracture suggest that the fractured zones are localized across the study area. While a negative Moran's I index value of -0.07 suggest that slope shows a disperse distribution pattern with each borehole location exhibiting a random slope value within the neighbouring location. The negative Moran's I index value of -0.04 for lineament suggest that the lineaments are in several sizes and directions in the study area. All the morpho-structural factors except regional structure show strong correlation with borehole yield. The weak correlation value of "-0.031" for regional structures indicates that it has little or no contribution to borehole yield in a typical schist belt terrain. This might be due to the influence of developed clayey filling resulting from deep weathering processes. The negative strong correlation value "-0.332" between geomorphological factor and borehole yield suggest that low borehole yield is associated with geomorphological units of high elevation (denudation hill, linear ridge, pediment inselberg complex), while geomorphological units (pediment and moderately weathered Pediplain) with low elevation will have high borehole yield. The positive correlation value "0.200" between lineament and borehole yield suggest that high lineament density is associated with high borehole yield indicative of active surface recharge mechanism that is prominent in Schist belts. The overall result demonstrates that integration of geophysics, remote sensing and spatial analysis to investigate the existence of relationship between Morpho-structural features and Borehole yield, can provide useful information as regards to groundwater exploration target with good yield in a typical crystalline basement rock.

Declaration of Interest

All the authors do not have any possible conflict of interest.

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