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Gullying Processes in the Upper Idemili River Catchment Area of Anambra State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Authors SNC, EIO and BCEE designed the study. Author SNC performed the statistical and graphical analysis and wrote the first draft of the manuscript. Authors EIO and BCEE wrote the protocol. Authors SNC, AGO and EA carried out geophysical data analysis. Authors SNC, EIO and BCEE managed the literature searches. All authors gave their approval for the final manuscript.

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ABSTRACT

Upper Idemili River catchment in Anambra State, Nigeria was studied for the effect of gullying processes in the area. The methods employed were fieldwork, Arc Gis production of digitized map which show the gully profile and laboratory analysis of soil and water samples. Hydrogeochemistry revealed acidic to slightly acidic water which is responsible for the decomposition of the cementing materials. The presence of the chemical species accounts for the dissolution of mineralogical and chemical composition of the rocks, and the different geochemical processes in the area. The bulk of the dissolved solid is attributed to geochemical reactions of oxidation-reduction and ion exchange reactions enhanced by acidic water. The chemical character of the water was employed to determine the water type using piper trilinear diagram and sodium bicarbonate (Na-HCO_3) water type was identified. A subdivision of the piper trilinear diagram indicates that the main water class is the one in which alkalis exceed alkaline earth elements and also dominated by sodium-bicarbonate type by 100% in each category. The high percentage of sodium water suggests possible ion exchange reaction that may lead to soil disaggregation. The hydraulic properties show

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that the soil material is porous, and permeable with high hydraulic conductivity which enhances gully development through an increase in water flow and its proneness to gully erosion. This study will create awareness on the importance of gully erosion and the need to take precautionary measures.

Keywords: Gullying; hydrogeological settings; Upper Idemili River; catchment; Anambra State; Nigeria.

1. INTRODUCTION

The earth surface is being ravaged by erosion into new forms. Gully processes cut into the land and groundwater flows out as spring where it intercepts the watertable. Seepage flow produces hydrologically active streams and rivers. These processes erode deep channels and valleys into the subsurface and some of the depressions are demarcated by a broad area of land drained by a single river and its tributaries or as lake. The effect of these processes produces new landscape when the sediments are transported and deposited in another location. Sediments transport on hillslope and fluvial geomorphology is recognized by Bryan [1]. Hence, gullying processes plays an important role in the reconstruction of landscape.

In river basins, groundwater dynamics often condition the spatial-temporal patterns of runoff generation and discharge. The impact on landscape evolution suggests that gully genesis and growth are closely related to the hydrogeological properties of a complex aquifer system [2]. Okoyeh et al. [3] reported that surface and subsurface water level dynamics were responsible for gully initiation and development in Anambra State. A study of the extent and distribution of groundwater by Nfor et al. [4] revealed a multi-aquifer system of confined and unconfined layers separated by aquitard in Anambra State. While, recent studies by Egbueri, et al. [5] revealed the impact of hydrogeomorphological characteristics on gullying processes in erosion-prone geological units in parts of southeast Nigeria. According to Egboka, [6] and Igbokwe et al. [7], gulling is one of the inherent geo-environmental problems in Southeastern, Nigeria and Anambra State has the highest number of gully sites with cases of new gully sites emerging annually.

Intensive gullying is most evident along the Awka-Orlu escarpment where headwater of streams and rivers has created deep valleys in the underlain geological material [8]. Awka-Orlu escarpment is saddled with an east facing gentle dip slope and a west facing steep scarp slope. The slopes are marked by series of gully lineament eroded into the subsurface by headwaters of the Imo and Mamu Rivers on the steep scarp slope and on the gentle dip slope by the Idemili and Orashi Rivers. Idemili River which drains the gentle dip slope has its headwaters emanating from the Oraukwu-Alor upland area and it is joined by several tributaries from the valley slope on its way downslope. Gulling processes accelerate the loss of soil and decrease in the productivity of agricultural land [9,10]. The eroded sediments are transported into receiving streams causing water quality deterioration and sedimentation problems.

The gullies of the Idemili river system and all other gullies of southeast Nigeria, originated as a response of the highly erodible sandy formations to the incisional regimes caused by base level changes following the Pleistocene glacio-eustatic sea level fluctuations [11]. Egboka, et al. [8] related the primary causes of gully genesis and growth to the hydrogeological and geotechnical properties of the complex aquifer system. Although, much work has been done to date, more studies are needed on the gullying processes in the upper Idemili River catchment area of Anambra State. This will be achieved through the determination of surface water and groundwater quality and the hydraulic characteristics of the soil material for their influence on gullying processes.

1.1 Location, Physiography and Geology

Latitude 6°'4"5 N to 6°8'4" N and Longitude 6°56'0" E to 7°1'6" (Fig. 1 and Fig. 2). It covers parts of Idemili South and Anaocha Local Government Areas of Anambra State. Major towns within the study area include Agulu, Adazi Nnukwu, Neni, Nnokwa Oraukwu, Alor and Abatete. These towns are accessible by footpath, untarred and tarred roads.

Prominent on the landscarp of southeasten region is the Awka-Orlu escarpment with steep scarp slope and a gentle dip slope which also form surface and groundwater divide. The excarpment is drain by a network of rivers, streams, and lakes. The major rivers include the eastward-flowing Odo and Manu Rivers, which flows into the Anambra River, and Orashi; Idemili Rivers which flows westward into the Nkisi River that discharges into the Niger River (Fig. 1). The drainage displays a dendritic pattern that is controlled by the topography and geology (Fig. 2). The geological settings consist of Nanka Formation underlain by Imo Shale and [12] (Fig. 3).

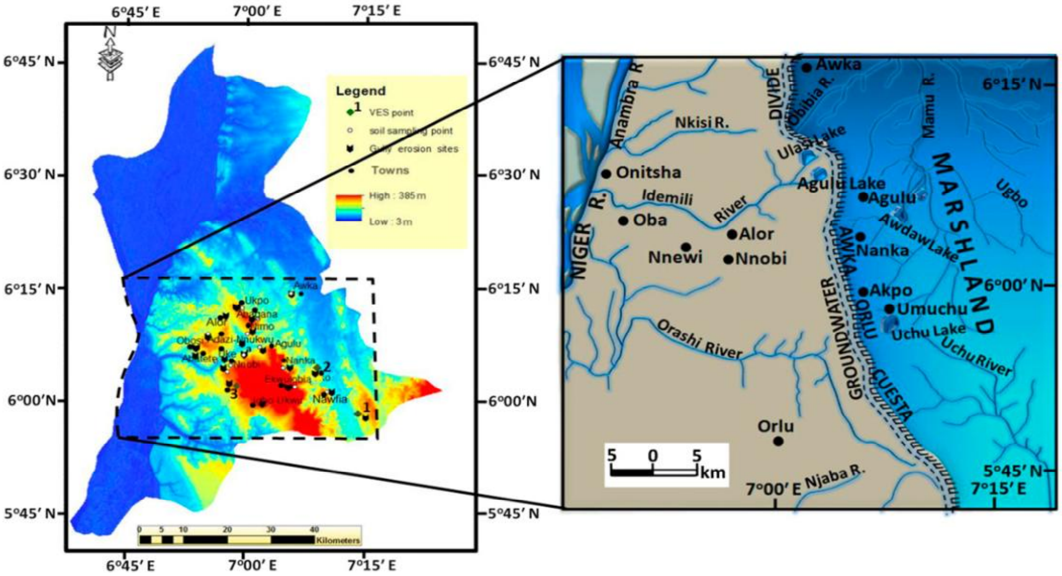


Fig. 1. Digitized drainage map of the study area (adapted from Okoyeh et al. [3])

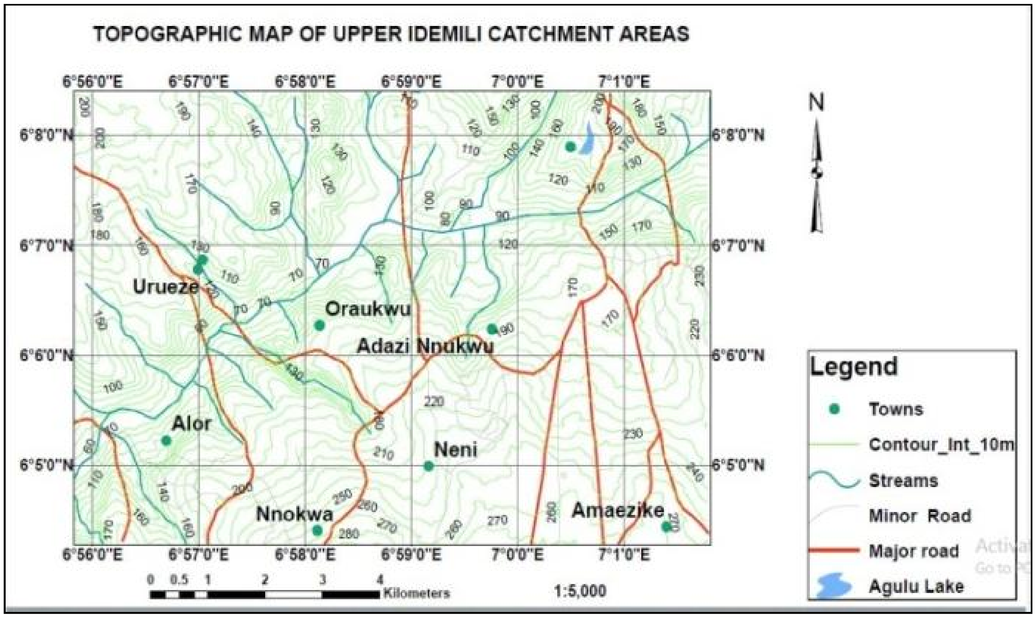


Fig. 2. Topography and drainage map of Upper Idemili drainage area

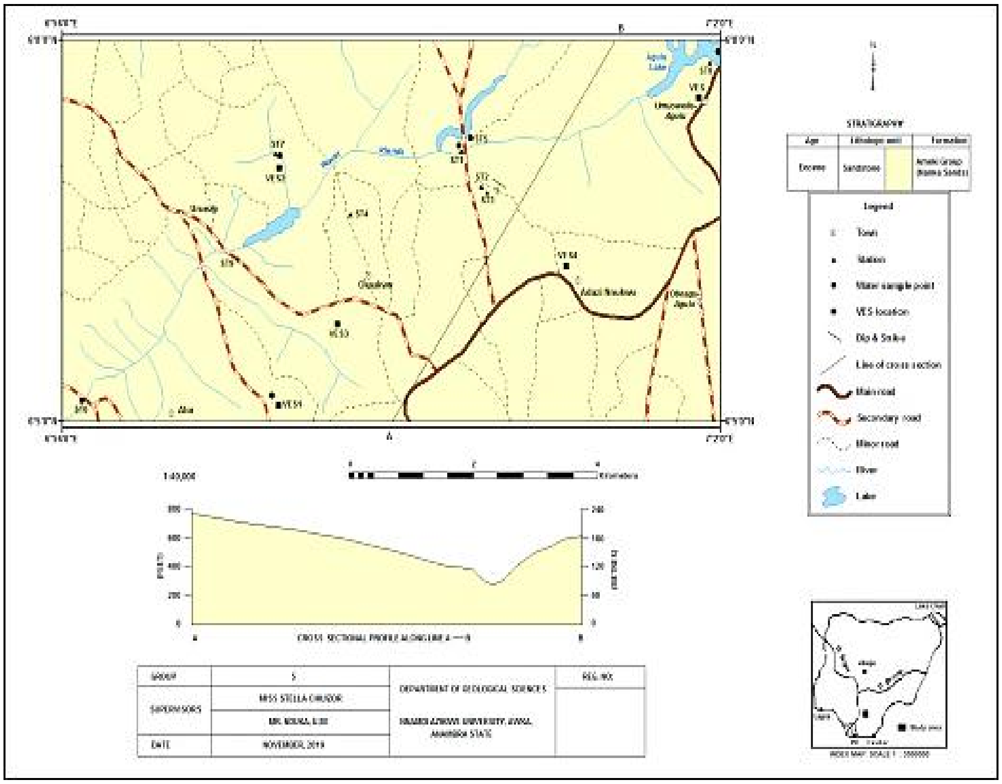


Fig. 3. Geologic map of the study area

2. MATERIALS AND METHODS

Six water samples were collected from the study area comprising of four surface waters and two groundwater samples (Table 1). The sample containers were flushed with phosphate-free detergents and rinsed with de-ionized water. They were thereafter rinsed with sample fluids prior to collection. The samples were adequately labelled, preserved in an ice chest and transported immediately to the laboratory for analysis. Three soil and three clay samples were also collected from one meter and two meters depth for particle size analysis and Atterberg limit test were carried out with clay samples.

The physiochemical parameters determined were; pH, electrical conductivity (EC), turbidity and total dissolved solids (TDS) and the concentration of the cations such as sodium (Na^+) and magnesium (Mg^{2+}) were determined using the Buck model 210/211 AAS graphite furnace and 220 AS Auto sampler while the anions such as chloride (Cl^-), sulphate (SO_4^{2+}), nitrate (NO_3^-), and carbonate (CO_3^-) were determined by digital titration. The heavy metals including iron, cadmium, chromium and arsenic were analyzed using the Buck model 210/211 GF graphite furnace and 220 AAS. Heavy metal analysis was conducted using Varian AA240 Atomic Absorption Spectrophotometer. The water types were determined using piper trilinear diagram of semi-log plot.

A total of five Vertical Electrical Sounding (VES) were carried out at different locations using the Schlumberger array with a maximum electrode spread of 200 m (Table 2). The VES data obtained were used to produce VES curves and geo-electric sections. The identification of auriferous regions in the study area was made possible by the application of the Vertical Electrical Sounding (VES) method.

2.1 Hydraulic Parameters

The derivatives of particle size distribution were used to calculate the uniformity coefficient for porosity computation and other hydraulic parameters were calculated as well.

Table 1. Water sample locations

s/n	Location	Type	Coordinate	Elevation
1	Along Nimo-Neni (Bridge)	Surface Water	N06º07'13.8" E006º59'43.5"	90 m
2	Nimo-Oraukwu (Opp,Tonimas)	Spring Water	N06º07'10.0" E006º59'37.0"	85 m
3	Alor-Abatete Road	Surface Water	N06º06'09.1" E006º57'20.1"	57 m
4	Alor	Groundwater	N06º55'12.4" E006º57'54.7"	176 m
5	Ezu-Amiagba Lakeabatete	Surface Water	N06º07'05.9" E006º57'59.2"	91 m
6	Agulu Lake	Surface Water	N06º07'58.7 "E007º02'02.7"	115 m

Table 2. VES points locations

s/n	VES locations	Coordinate	Elevation
1	Umunambo-Alor	N06º05'07.2" E006º57'58.7"	196 m
2	Amankpume Nsukwu -Abatete	N06º06'59.3" E006º57'58.7"	147 m
3	Umudim-Oraukwu	N06º05'46.3" E006º58'29.9"	172 m
4	Eke Adazi Nnukwu	N06º06'13.4" E007º00'35.3"	177 m
5	Umuawele Agulu	N06º08'10.3" E007º02'04.0"	137 m

2.1.1 Porosity (*n*)

Porosity values were obtained from the empirical relationship between standard values and the uniformity coefficient of grain (C_U) according to Vukovic and Soro [13] as follows:

$$n = 0.255(1 + 0.83^{U}) \quad (1)$$

Where n is porosity, u is the uniformity coefficient.

2.1.2 Hydraulic conductivity (*K*)

Hydraulic conductivity was computed using the Krumbein and Monk [14] equation to calculate for permeability (*k*) which was substituted into the hydraulic conductivity (*K*) Equation as follows,

$$k = 760(M)^2\, e^{(-1.31 Q\emptyset)} \quad (2)$$

where *k* is the intrinsic permeability in Darcy, *M* = geometric mean grain diameter (mm) and $Q_{\emptyset}$ is the standard deviation of grin diameter in ø units.

Hence,

$$K = \frac{k\delta g}{\mu} \quad (3)$$

Where *K* is hydraulic conductivity (cm/sec),
$\delta = 0.9982\frac{\mathrm{g}}{\mathrm{cm}^3}$ is the density of water at 20°C,
$k = 9.87\text{x } 10^{-9}\ \frac{\mathrm{cm}^2}{\mathrm{darcy}}$ is the intrinsic permeability conversion factor,
$\mu = 0.01\mathrm{g}\ (\frac{\mathrm{cm}}{\mathrm{sec}})$ 20°C is the dynamic viscosity of water and;
g is the gravity acceleration value.

2.2 Atterberg Limit Test

The Atterberg test was used to determine the strength of the soil at different limits depending on the moisture content of the soil. The moisture contents at these boundaries are known as the: Liquid limit (LL), Plastic limit (PL) and Plasticity Index (PI).

2.2.1 Plastic limit (PL)

Plastic limit is the minimum moisture content at which the soil was rolled into a thread of 3 mm diameter without breaking and then oven dried at 150°C and re-weigh.

2.2.2 Liquid limit (LL)

Liquid limit is the water content at which the soil behaves like a liquid which was obtained at the 25th blow from the liquid limit chart.

2.2.3 Plasticity index (PI)

This is the difference between the liquid limit and plastic limit and is expressed mathematically as;

$$PI = LL - PL \quad (4)$$

3. RESULTS AND DISCUSSION

The Upper Idemili catchment area is located on the Awka-Orlu escarpment/cuesta which is the main topographic expression of the Nanka Formation in Anambra State. The formation has been severely gullied and most of the gullies site form headwaters of streams and rivers.

Particularly important is the Idemili River flowing on the gentle dip slope of the cuesta, the river is very extensive and occupies a very deep valley. The valley slopes are dissected by moderate to deep lines of gullies that are orthogonal in altitude to the river. Most of the valley lines are marked by headwaters of streams such as the Mmiri Nwocha in Oraukwu, Mmiri Okide, Mmiri Iyi-Ogwugwu, Ide-Ofala and Mmiri-Eziegbo in Alor and the presence of lakes such as Agulu lake, Ezu-Amiagba lake Abatete, Ochi-iyi Alor which hold some of the surface runoff. Idemili River is also called mmiri Obiaja in Alor meaning water emanating from the heart of the Oraukwu-Alor upland area. The Idemili River catchment area as seen from the digital elevation model (DEM) display a dendritic drainage pattern with the main river valley in the central region with its tributaries (streams/river) and flanked by highland to the east and west directions (Fig. 4). The highland area coincides with areas of intensive gully erosions/mass wasting and groundwater discharge zones. Their hydraulic activities influence the gullying processes which facilitates gully and landslide development in the study area. Several gully profiles A-A, D-D across the river trunk and F-F, G-G on the valley flanks show gully incisions/features on the dip slope of the escarpment which indicates active gullying at groundwater discharge area (Fig. 5).

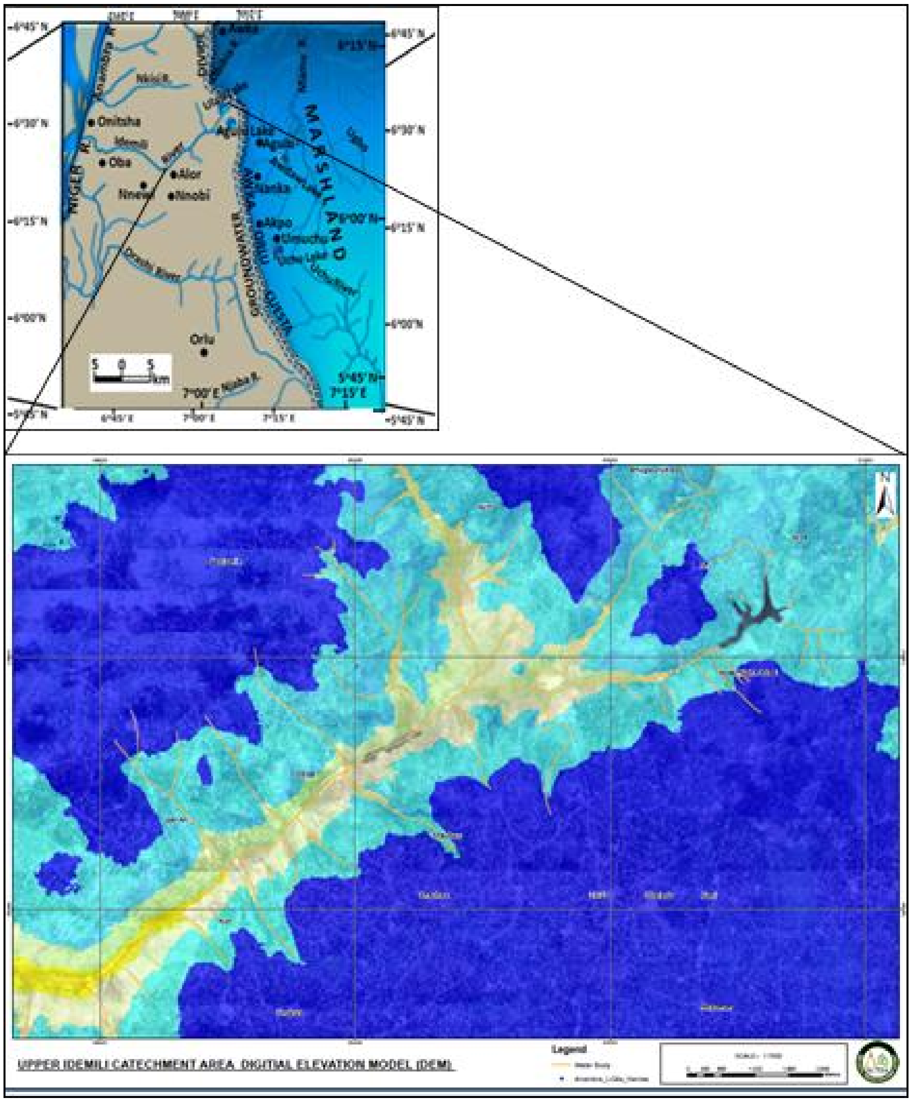


Fig. 4. Upper Idemili catchment area digital elevation model (DEM)

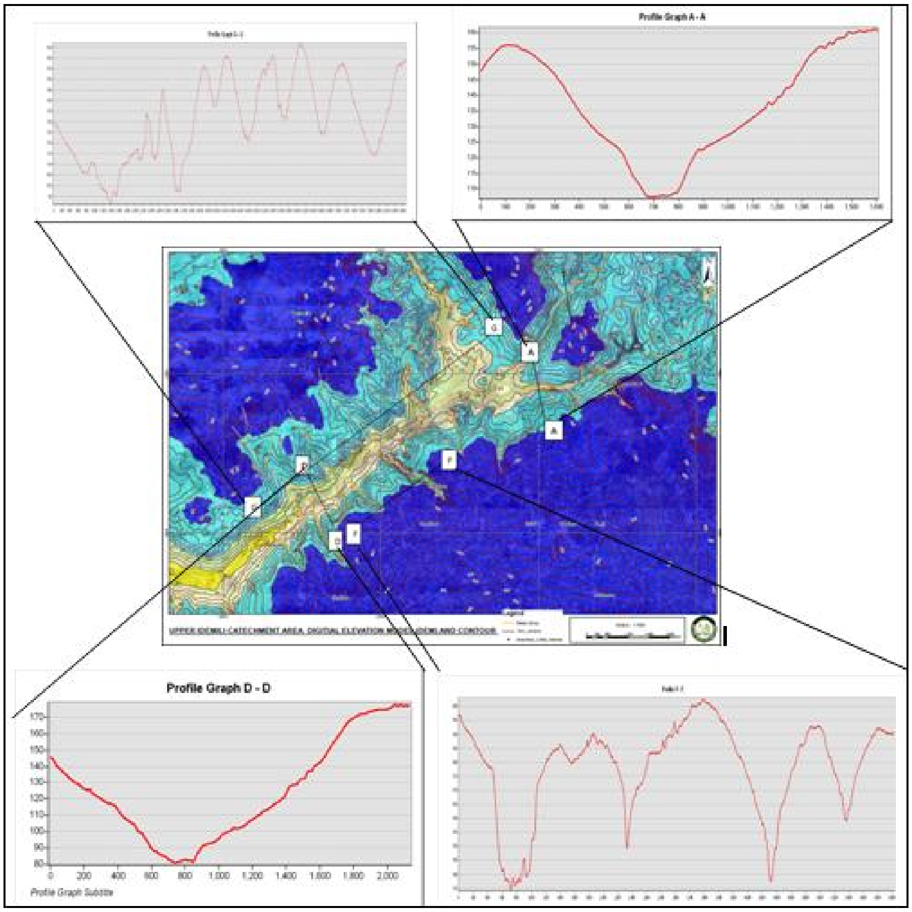


Fig. 5. Gully profiles of some areas

3.1 Hydrogeochemistry

Water samples from surface water and groundwater were analyzed for physiochemical properties to determine their contribution to gully development. The pH values range from 5.27 to 6.40 with average value of 5.88 for surface water and uniform value of 5.48 in all the groundwater samples which indicates acidic to slightly acidic water. Such acidic water may lead to the decomposition of the cementing materials and hence, erodibility of the soil. On the other hand, the electrical conductivity for surface and groundwater values range from 30.1 µs/cm to 72.1 µs/cm and 40.0 µs/cm to 54.3 µs/cm respectively. The electrical resistivity value is a summarizing parameter which reflects the total dissolved solid (TDS) in a water body. This is reflected in the results of the total dissolved solid (TDS), which show a range of 40.0 mg/l to 150.0 mg/l and 70.0 mg/l to 140.0 mg/l in surface water and groundwater respectively. These values reflect the large content of soluble ions particularly inorganic present in the water sources. The turbidity values vary from 0.7 nephelometric turbidity unit (NTU) to 2.1 NTU and 1.3 NTU to 2.3 NTU for surface waters and groundwater, hardness values range from 32 mg/l to 52 mg/l and 36 mg/l to 40 mg/l in surface water and the groundwater respectively (Table 3).

3.1.1 Chemical parameters (inorganic elements and heavy metals)

Chemical analysis of surface water and groundwater samples show that sodium concentration varying between 0.02 ppm to 4.68 ppm and from 0.67 ppm to 2.05 ppm similarly, magnesium values varied between 0.01 ppm to 3.12 ppm and 0.69 ppm to 1.97 ppm which is an indication of elements from the clay family and possible ion-exchange reaction; For the anions, the concentration of carbonate observed in the area range between 38 mg/l to 65 mg/l and from 42 mg/l to 50 mg/l, nitrate concentration vary from 5.32 mg/l to 7.49 mg/l and 8.37 mg/l to 11.39 mg/l, sulphate concentration ranges from 3.39 mg/l to 4.53 mg/l and 3.66 mg/l to 3.72 mg/l. while iron values ranged from 0.28 ppm to 0.60 and 0.41 ppm to 0.46 ppm, which is an indication of geochemical processes of oxidation-reduction reactions. Chloride is the most abundant element in the study area and value ranges from 24 mg/l to 35 mg/l and 37 mg/l to 40 mg/l in surface waters samples groundwater respectively which suggest intrusion of seawater within the study area. This study recorded relatively low concentrations of heavy metals within the study area with arsenic recording the highest values of 8.57 ppm to 10.30 ppm and 8.12 ppm to 9.97 ppm in the surface and groundwater samples respectively. Cadmium and chromium however showed their highest concentrations in groundwater with values ranging from 0.04 ppm to 0.04 ppm and 0.17 ppm to 0.40 ppm respectively. Their concentration in the surface water bodies ranged from 0.00 ppm to 0.06 ppm in cadmium and 0.00 ppm to 0.93 ppm in chromium. The bulk of the dissolved solid maybe attributed to geochemical reactions of oxidation-reduction and ion exchange reactions enhanced by acidic water.

The chemical character of the water was employed to determine the hydrochemical facies and compositional percentage/class using the piper trilinear diagram [16] for this study as presented on (Fig. 6). Sample points with similar chemical characters tend to cluster together in a distinct region called hydrchemical facies and sodium bicarbonate (Na-HCO_3) water type was identified. In order to define the compositional class based on Back and Hanshaw [17] subdivision of the piper tri-linear diagram (Table 4), the main water class in the study area is the one in which alkalis exceed alkaline earth elements and also dominated by sodium-bicarbonate type by 100% in each category. The high percentage of sodium water suggests possible ion exchange reaction that may lead to disaggregation of the soil structure. This could be due to the effect of precipitation and mineral dissolution from the geology of the area.

Table 3. Result of the physical and chemical parameters and the WHO (2012) [15] standards

Parameters	1	2	3	4	5	6	WHO standard
pH	6.35	5.48	5.53	5.48	5.27	6.40	6.5-8
Conductivity us.cm	30.1	40.0	42.4	54.3	72.1	40.3	1000
Turbidity NTU	2.1	2.3	0.7	1.3	1.2	2.0	5
TDS mg/l	70	140	60	70	150	40	600
Chloride mg/l	30	40	35	37	35	24	250
Hardness mg/l	32	40	52	36	34	52	<100
Sulphate mg/l	4.28	3.66	4.53	3.72	4.36	3.39	250
Nitrate mg/l	5.89	8.37	5.32	11.39	6.17	7.49	50
Carbonate mg/l	45	50	65	42	38	65	
Magnesium ppm	3.07	0.69	0.01	1.97	3.11	0.09	20
Cadmium ppm	0.00	0.04	0.00	0.04	0.06	0.00	0.003
Chromium ppm	0.93	0.40	0.07	0.17	0.00	0.14	0.05
Iron ppm	0.60	0.41	0.51	0.46	0.78	0.28	0.3
Sodium ppm	4.11	0.67	0.02	2.05	4.68	0.29	200
Arsenic ppm	10.30	9.97	9.95	8.12	8.57	9.90	0.01

Table 4. Characterisation of water samples in the study area using Back and Hanshaw, [17] subdivision

s/n	Characteristics of the subdivisions in the diamond	Percentage of samples in the category
1	Alkaline earth (Ca +Mg) exceed alkalis (Na + K)	nil
2	Alkalis exceed alkaline earths	100
3	Weak acid (CO3 + HCO3) exceed strong acid (SO4 + Cl)	100
4	Strong acids exceed weak acids	nil
5	Magnesium bicarbonate type	nil
6	Calcium-chloride type	nil
7	Sodium-chloride type	nil
8	Sodium-bicarbonate type	100
9	Mixed type (No cation –anion pairs exceeds 50%)	nil

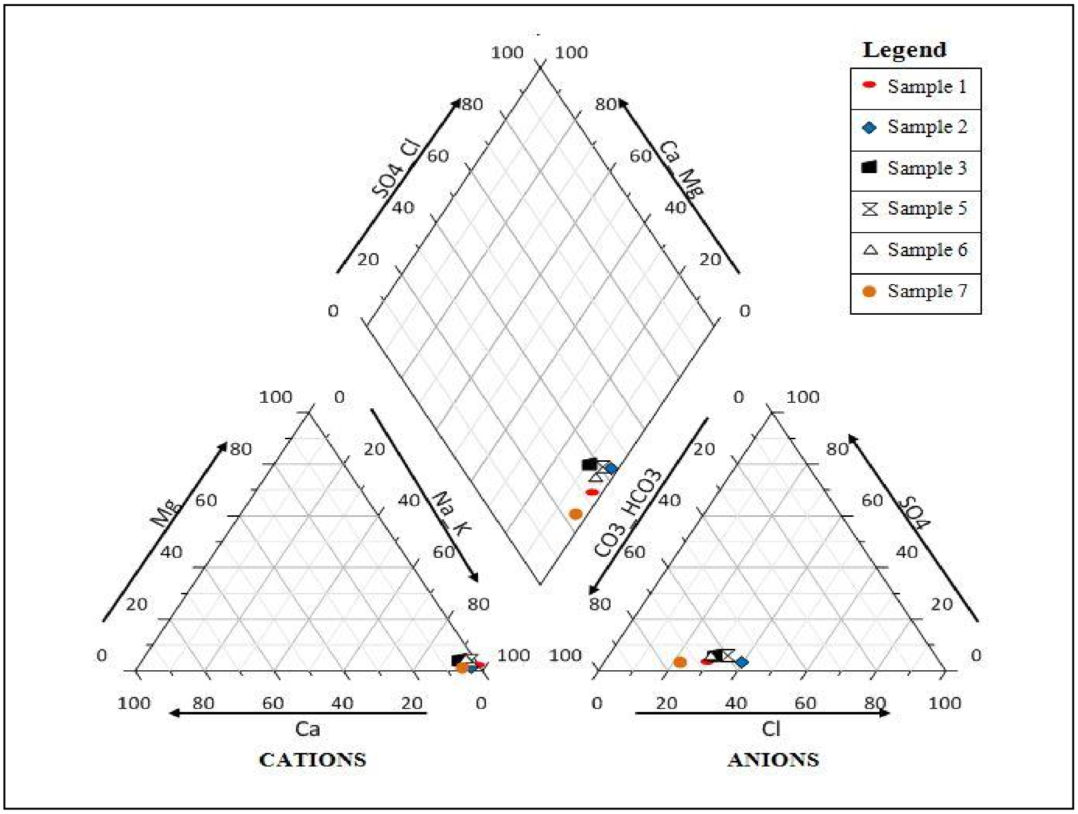


Fig. 6. Piper Trilinear diagram for water samples

3.2 Hydraulic Characteristics

The particle distribution analysis shows a uniformly graded soil with fine grained 34%, medium grained 65% and coarse grained 1% from the particle size distribution graph (Fig. 7).

The hydraulic parameters for soils at 1 and 2 meters depth and the drilled cuttings from borehole show porosity (*n*%) values range from 29% to 42%, 36% to 38% and 35 to 43% respectively, permeability (*k*) values range from 9.95E-07 to 3.04E-05 (cm/s) with average value of 1.50E-05 (cm/s), 2.86E-06 to 7.74E-06 (cm/s) with average value of 4.35E-06 (cm/s) and 3.46E-06 to 7.71E-06 with average value of 3.54E-06 respectively, hydraulic conductivity (*K*) values range from 9.77E-06 to 2.99E-04 (cm/s) with average value of 1.47E-04 (cm/s), 2.80E-05 to 7.60E-05 (cm/s) with average value of 4.27E-05 (cm/s) and 3.77E to 8.8.40E-03 with average value of 3.85E-03 (Table 5) and (Table 6). Other parameters calculated for the drilled cutting from borehole at Nwagu-Agulu includes specific discharge(Vd) values range from 1.89E-04 to 4.20E-04 with average value of 1.93E+00, transmissivity (T) values range from 8.67E-01 to 1.93E+00 with average value of 8.86E-01, average linear groundwater discharge velocity (Va) values range from 4.72E-01 to 9.84E-04 with average value of 6.52E-04 and discharge values range from 4.33E-02 to 9.65E-2 with average value of 6.16E-0. These values were compared with the range of values for permeability and hydraulic conductivity of different sediments given by Freeze and Cherry [18] and it shows that the soil material is porous, and permeable with high hydraulic conductivity can transmit water. High values of hydraulic conductivity enhance gully development through an increase in water flow and erodibility of the soil grains.

The result of the Atterberg limits test of soil samples show liquid limit values of 83%, 59% and 51%, the plastic limit values are 41%, 23% and 19% and the plasticity index values are 42%, 36% and 32%. These values are represented on (Table 7) and the semi-log graph plot of liquid limitis test is presented on (Fig. 8). All samples tested show medium plasticity when compared with the reference values for consistency limits

[19,20]. The grain size analysis result combine with the Atterberg limit test results aided the classification of the soil as silty/clayey sand. This indicates that the soil is capable of absorbing water which can lead to expansion and contraction of the clayey materials. In the process of changing in size according to the prevalent hydrological conditions, the clays lose their shear strength leading to soil instability and slope failure/gully development.

3.3 Delineation of Geo-electric Layers and Interpretation of VES Data

The resistivity and depth data obtained from Vertical Electrical Sounding (VES) were used to produce VES model of geo-electric sections in the study areas. Qualitative interpretation of the VES model shows about six geo-electric layers of top soil/laterite, clayey-sand, shale, sand, sandstone and water saturated sand (Table 8).

The resistivity values of the top soil vary from 12.10 to 116.73 Ω-m with average value of 53.61 Ω-m and thickness value ranges from 2.21 to 3.74 m, with average value of 2.74, clayey sand value ranges from 23.16 to 1119.79 Ω-m with average value of 437.56 Ω-m and thichness value ranges from 6.43 to 27.54 with average value of 12.37 m, sand value ranges from 210.32 to 1821.00 Ω-m with average value of 886.70 Ω-m and thickness value range 6.86 to 48.12 m with average value of 29.36 m, shale value ranges from 22.67 to 37.09 Ω-m with average value of 27.64 Ω-m and thickness value ranges from 12.88 to 42.26 m with average value of 23.90 m, dry sandstone value ranges from 704.82 to 5378.30 Ω-m with average value of 3361.49 and thickness value ranges from 40.94 to 91.13 m with average value of 62.52 m saturated sandstone value range from 406.02 to 2022.47 and base not reach.

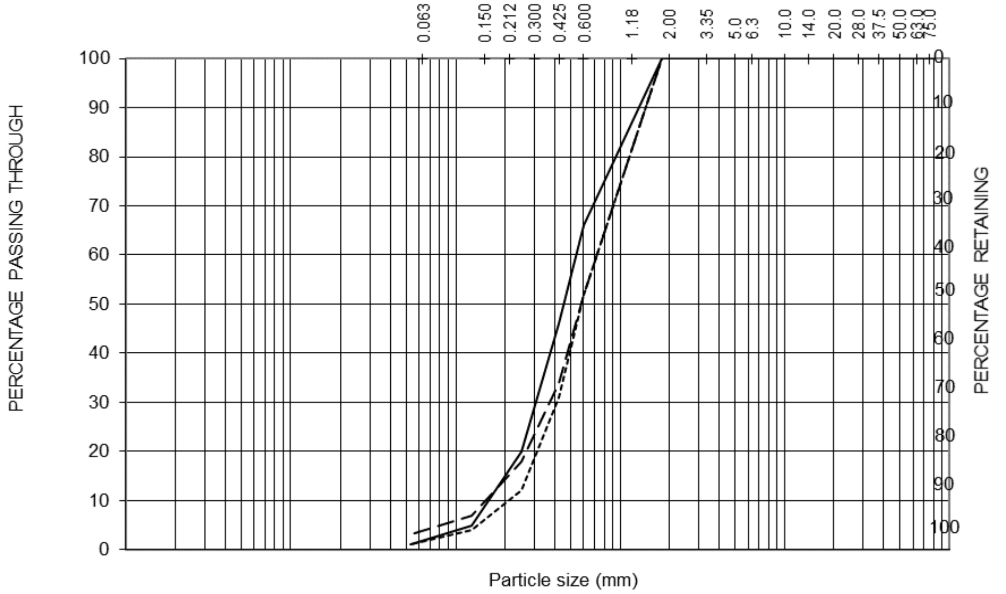


Fig. 7. Particle size distribution graph

Table 5. Hydraulic parameters

Samples	1 meter depth			2 meters depth		
	n%	k(cm/s)	K(cm/s)	n%	k(cm/s)	K(cm/s)
Umuru Ide Alor	39	1.28E-05	1.26E-04	38	3.44E-06	3.38E-05
Nimo	42	3.04E-05	2.99E-04	38	7.74E-06	7.60E-05
Oraukwu	29	9.95E-07	9.77E-06	36	2.86E-06	2.80E-05
Nnobi Comm. School	40	1.57E-05	1.55E-04	37	3.37E-06	3.31E-05

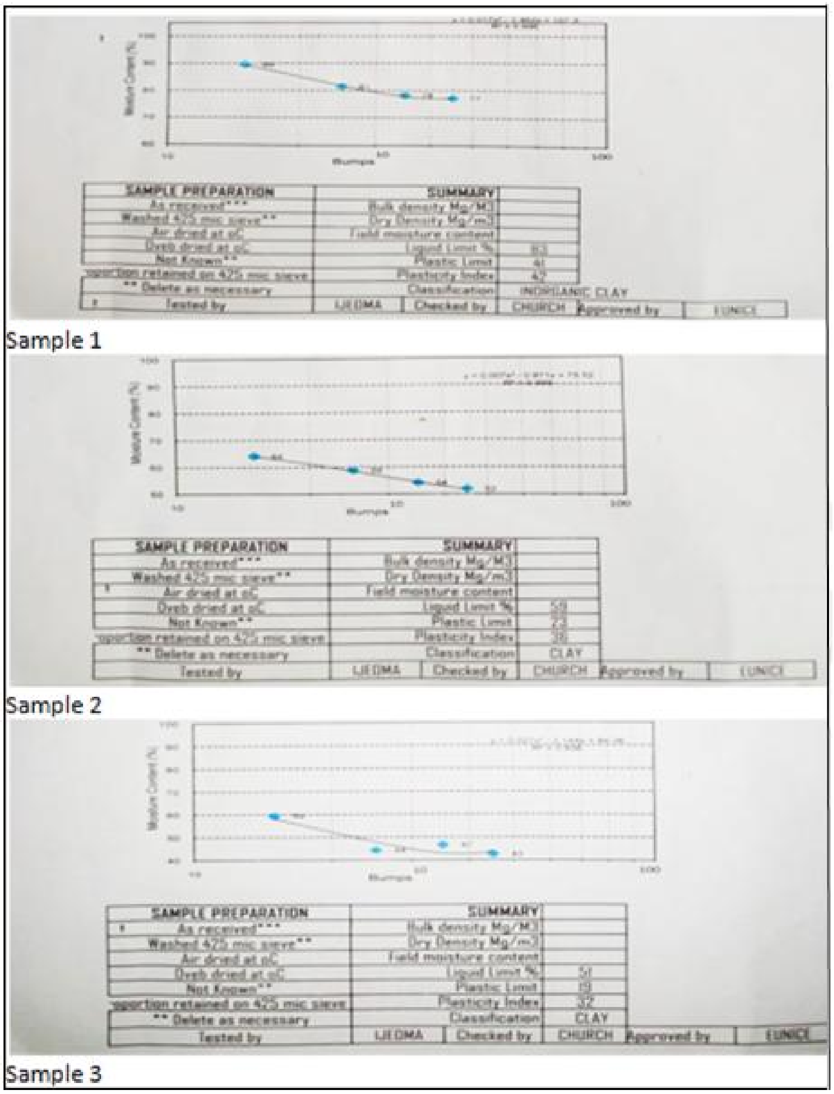
Table 6. Hydraulic parameters estimated for drilled cuttings from borehole (Nwagu-Agulu)

Depth (m)	*Cu*	*n*%	*k*(m/s)	*K*(m/s)	*Vd*	*T*(m/s)	*Va*(m/s)	*Q*(m/s)
37.1	3.04	40	3.46E-06	3.77E-03	1.89E-04	8.67E-01	4.72 E-04	4.33E-02
101.1	5.29	35	3.61E-06	3.93E-03	1.97E-04	9.05E-01	5.62 E-04	4.52E-02
181.5	2.13	43	7.71E-06	8.40E-03	4.20E-04	1.93E+00	9.84 E-04	9.65E-02
*Ave			3.54E-06	3.85E-03	1.93E+00	8.86E-01	6.52E-04	6.16E-02

**Ave is average*

Table 7. Results Atterberg limit test

Sample	Sample 1	Sample 2	Sample 3
Liquid Limit (%)	83	59	51
Plastic Limit (%)	41	23	19
Plasticity Index (%)	42	36	32



SAMPLE PREPARATION	SUMMARY				
As received***	Bulk density Mg/M3				
Washed 425 mic sieve**	Dry Density Mg/m3				
Air dried at oC	Field moisture content				
Oveb dried at oC	Liquid Limit %	83			
Not Known**	Plastic Limit	41			
oportion retained on 425 mic sieve	Plasticity Index	42			
** Delete as necessary	Classification	INORGANIC CLAY			
Tested by	UEDMA	Checked by	CHURCH	Approved by	EUNICE

Sample 1

SAMPLE PREPARATION	SUMMARY				
As received***	Bulk density Mg/M3				
Washed 425 mic sieve**	Dry Density Mg/m3				
Air dried at oC	Field moisture content				
Oveb dried at oC	Liquid Limit %	59			
Not Known**	Plastic Limit	23			
oportion retained on 425 mic sieve	Plasticity Index	36			
** Delete as necessary	Classification	CLAY			
Tested by	UEDMA	Checked by	CHURCH	Approved by	EUNICE

Sample 2

SAMPLE PREPARATION	SUMMARY				
As received***	Bulk density Mg/M3				
Washed 425 mic sieve**	Dry Density Mg/m3				
Air dried at oC	Field moisture content				
Oveb dried at oC	Liquid Limit %	51			
Not Known**	Plastic Limit	19			
oportion retained on 425 mic sieve	Plasticity Index	32			
** Delete as necessary	Classification	CLAY			
Tested by	UEDMA	Checked by	CHURCH	Approved by	EUNICE

Sample 3

Fig. 8. Graph of liquid limits

Shale has a low resistivity and does not easily transmit fluid while, the sand and sandstone have high resistivity and allows fluid flow. This may favour high flow rate of groundwater and hence, erodibility of the soil. The depth to water level varies from 60.56 to 129.24 and elevations along the length of the main river (Idemili River) exposed at different locations; Nimo-Oraukwu bridge, Oyemioku-Oraukwu and mmiri Obiaja-Alor are 90 m, 74 and 57 m respectively. The depths to water table and elevations were used to determine the direction of groundwater flow. Considering, the areas of low water levels, the flow is from east to west and north to south. This is facilitated by the high resistivity of the sand and sandstone units of the geological formation thereby accelerating gully erosion and landslides development. Thus, water level rise enhances groundwater flow intensity and gullying processes in the area. The modelled curves with the interpreted layers, resistivity, layer thickness and inferred lithologic units are represented on (Figs. 9 and 10). The regional correlation of the geo-electric sections and water saturated sand with the watertable (VES 1, 2, 3, 4, and 5) across the study area is represented on (Fig. 11).

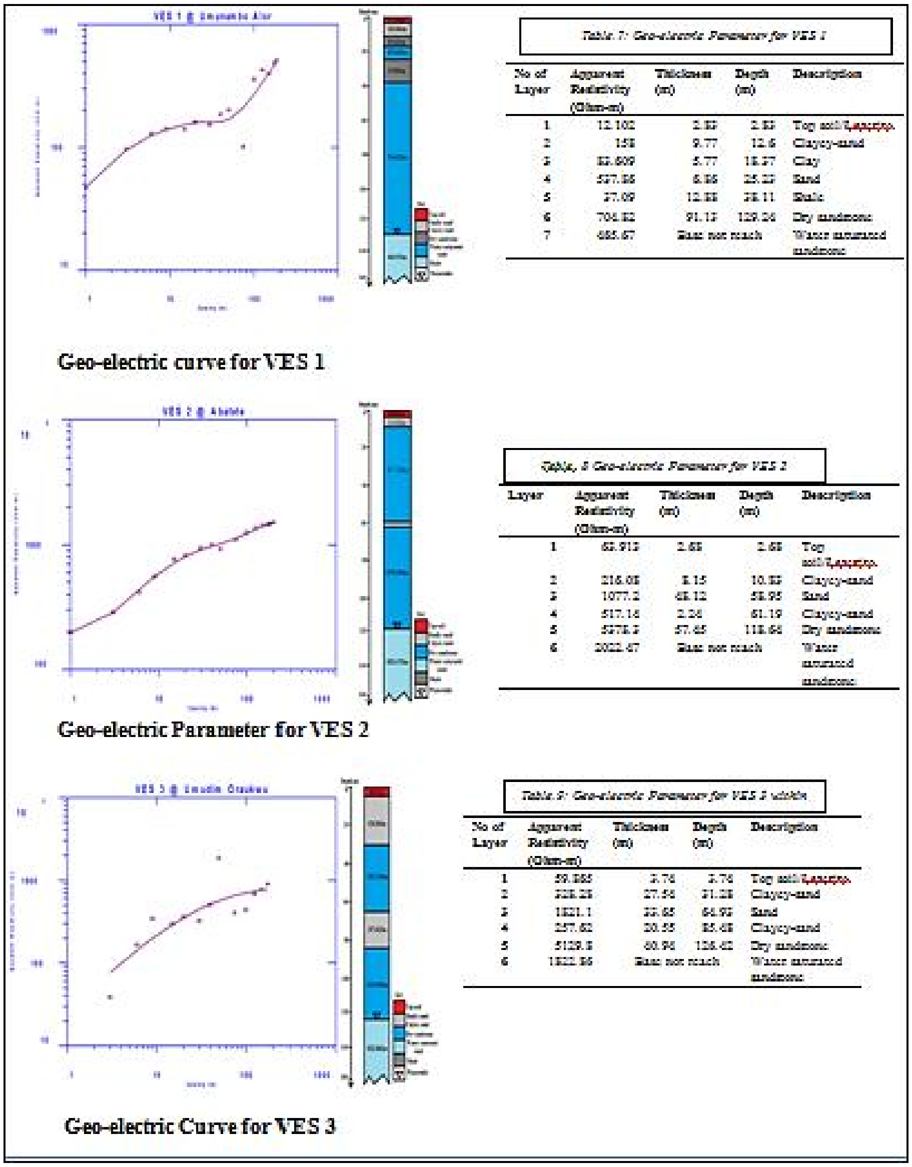


Table 7: Geo-electric Parameter for VES 1

No of Layer	Apparent Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Description
1	12.102	2.83	2.83	Top soil/Laterite
2	158	9.77	12.6	Clayey-sand
3	52.609	5.77	18.37	Clay
4	527.86	6.86	25.23	Sand
5	27.09	12.88	38.11	Shale
6	704.82	91.13	129.24	Dry sandstone
7	685.67	Base not reach		Water saturated sandstone

Geo-electric curve for VES 1

Table, 8 Geo-electric Parameter for VES 2

Layer	Apparent Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Description
1	63.913	2.68	2.68	Top soil/Laterite
2	216.08	8.15	10.83	Clayey-sand
3	1077.2	48.12	58.95	Sand
4	517.16	2.24	61.19	Clayey-sand
5	5378.3	57.45	118.64	Dry sandstone
6	2022.47	Base not reach		Water saturated sandstone

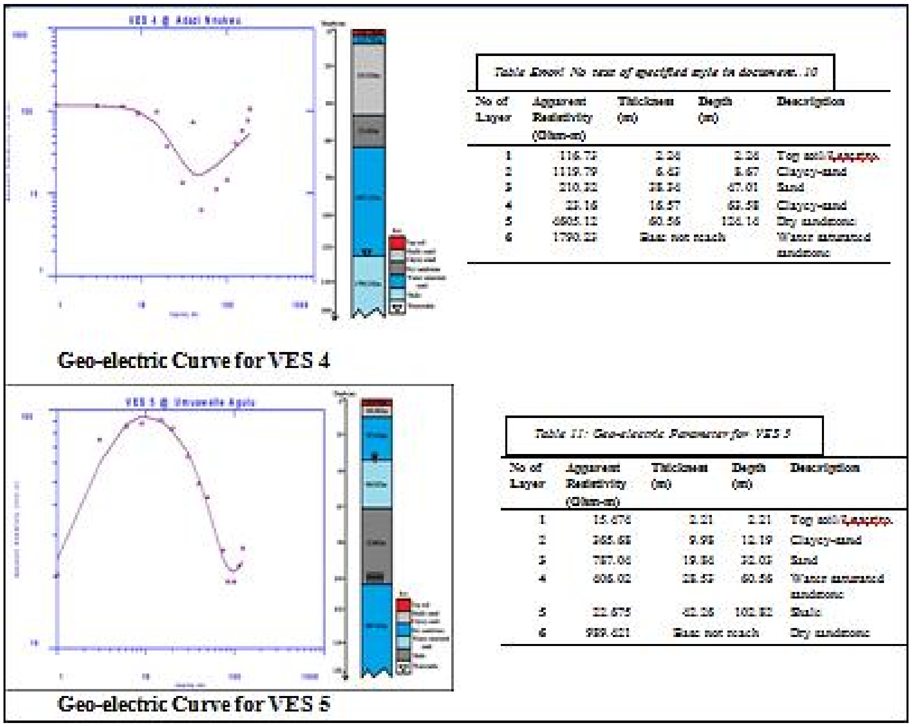
Geo-electric Parameter for VES 2

Table 9: Geo-electric Parameter for VES 3 within

No of Layer	Apparent Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Description
1	59.885	3.74	3.74	Top soil/Laterite
2	228.28	27.54	31.28	Clayey-sand
3	1821.1	33.65	64.93	Sand
4	257.62	20.55	85.48	Clayey-sand
5	5129.8	40.94	126.42	Dry sandstone
6	1822.86	Base not reach		Water saturated sandstone

Geo-electric Curve for VES 3

Fig. 9. Geo-electric curves for VES 1, 2 and 3



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No of Layer	Apparent Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Description
1	116.72	2.24	2.24	Top soil/Laterite
2	1119.79	6.43	8.67	Clayey-sand
3	210.32	38.34	47.01	Sand
4	23.16	16.57	63.58	Clayey-sand
5	4605.12	60.56	124.14	Dry sandstone
6	1790.23	Base not reach		Water saturated sandstone

Table 11: Geo-electric Parameter for VES 5

No of Layer	Apparent Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Description
1	15.676	2.21	2.21	Top soil/Laterite
2	365.68	9.98	12.19	Clayey-sand
3	787.04	19.84	32.03	Sand
4	406.02	28.53	60.56	Water saturated sandstone
5	22.675	42.26	102.82	Shale
6	989.421	Base not reach		Dry sandstone

Fig. 10. Geo-electric curves for VES 4 and 5

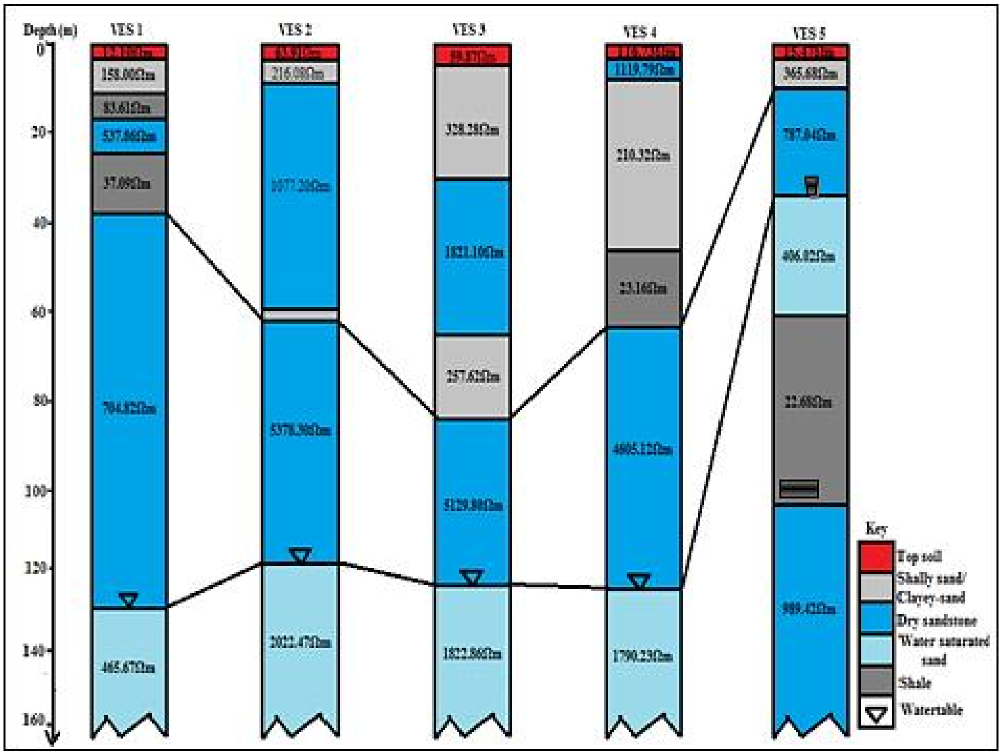

Fig. 11. Correlation of the geo-electric sections for VES 1, 2, 3, 4 and 5

Table 8. Inferred geologic and range of values of geo-electric parameters

Lithology	Resistivity Ω-m		Thickness (m)		Depth (m)	
	Range	Average	Range	Average	Range	Average
Topsoil/Laterite	12.10-116.73	53.61	2.21-3.74	2.74	2.21-3.74	2.74
Clayey sand	23.16-1119.79	437.56	6.43-27.54	12.37	8.67-31.28	15.11
Sand	210.32-1821.00	886.70	6.86-48.12	29.36	25.23-64.93	45.63
Shale	22.67-37.09	27.64	12.88-42.26	23.90	38.11-102.82	68.17
Dry sandstone	704.82-5378	3361.49	40.94-91.13	62.52	118.64-129.24	124.61
Saturated sand	406.02-2022.47	1301.45	base not reach		base not reach	

4. CONCLUSION

The Hydrogeochemistry data revealed slightly acidic water and high levels of dissolved metals with predominance of sodium bicarbonate water type. The presence of sodium water type is an indication of geochemical processes of ion exchange reactions and mineral dissolution. This may lead to decomposition of the cementing material and loosening of the soil grain to erosion. The susceptibility of the soil to erosion is also comprehended by the weak, porous and permeable materials of high hydraulic conductivity. The high conductivity enhances high rate of groundwater flow and hence, erodibility of the soil. The Atterberg limit test of liquid, plastic and plasticity for the clays show moderate to slightly plasticity, which indicates that the soil is capable of absorbing water. Such process will lead to expansion and contraction of the clayey materials which in turn, will reduce the shear strength of the material leading to instability that is detrimental to slope failure.

The VES models provide an understanding of depth/thickness of the aquifers and the individual geologic units of low and high resistivity. The high resistivities of the transmitting zones allow groundwater flow. Seepage flow enhance by the permeable medium and the surface water system influence the gullying processes in the area. Therefore, groundwater hydraulic activities exact a strong impact on gullying processes in the study area.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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