Hydrochemical and Geological Investigations of Some Gully Erosion-Prone Areas in Parts of Awka-Orlu Cuesta, Nigeria

Stella Nwaife Chibuzor (✉ sn.chibuzor@unizik.edu.ng)  
Nnamdi Azikiwe University

Boniface Chukwukadebia. E. Egboka  
Nnamdi Azikiwe University

Emma Kenechukwu Anakwuba  
Nnamdi Azikiwe University

Evagenline Njideka Onuigbo  
Nnamdi Azikiwe University

Ovie Odokuma-Alonge  
University of Benin

Ogechukwu Anastasia Ben-Owope  
Materials Testing Laboratory,

Akudo Ernest Orji  
Federal University Lokoja

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Abstract

Gullies of the Awka-Orlu escarpment within Anambra State, Nigeria, were studied using hydrochemical and geological properties for understanding the geo-environmental problems which underlies the gully-prone areas. This was achieved by conducting fieldwork which includes mapping, hydrogeological surveys and samples collection, followed by laboratory analyses of soil and water samples. The soil samples were subjected to particle size analysis, compaction. Water samples were analyzed using atomic absorption spectrophotometer and titrimetric methods. The results of surface water and groundwater revealed pH average values of 5.99 and 6.3, indicating slightly acidic. Such slightly-acidic water facilitates decomposition of the cementing material in the soil. The chemical composition of surface water revealed average concentrations of magnesium (1.57 mg/l), calcium (3.40 mg/l), sodium (2.27 mg/l), chloride (22.28 mg/l), iron (0.38 mg/l), bicarbonates (37.85 mg/l), nitrate (4.73 mg/l), sulphate (3.81 mg/l), for groundwater magnesium (2.57 mg/l), calcium (3.50 mg/l), sodium (2.26 mg/l), chloride (15.09 mg/l), iron (0.23 mg/l), bicarbonates (25.46 mg/l), nitrate (11.61mg/l), sulphate (8.49mg/l) and total dissolved solid (TDS) average values of 63.16mg/ and 50.90mg/l. Using the cations and anions values to plot the piper trilinear diagram sodium bicarbonate (Na-HCO$_3$). This is attributed to geochemical reactions of ion-exchange and oxidation-reduction in the soil. These reactions contribute to soil disaggregation, erosion and destruction of engineering structures build to control gully erosion. water type was identified. The soil is permeable with good infiltration capacity. The investigations showed the vulnerability of the soil to gullying. These findings are important for any planned, well-designed and executed gully erosion control programmes.

1. Introduction

Erosion is the detachment of earth materials due to gravity and fluid flow which occurs commonly as sheeting, rilling and gulling. Gully form of erosion is aided by concentrated water and flood flow. It starts with an initial narrow incision that is subsequently enlarged by headward erosion and mass movement into the subsurface. The instigation factors has been attributed to climate (Lanckriet et al., 2013, Poesen et al., 2003), topography (Pourghasemi et al., 2017 and Valentin et al., 2005), geology and hydrogeology (Igwe., 2018; Conforti et al., 2011; Amah et al., 2008; Valantin, 2003; Egboka et al., 1984, 1985; and Nwajide., 2013).Gully erosion phenomenon is considered to be a natural event that is affected by a wide array of factors that destroys the land with devastating effects on the environment.

Land devastation associated with gully erosion is a global problem. Gully erosion affects agriculture, human habitation, natural resources such as surface and groundwater resources, vegetation and land. Most lands that are subjected to gully erosion are of little significant use and are regarded as waste land. This situation is found in semi-arid regions that are unsuitable for agriculture (Salleh and Mousazadeh, 2011) and humid tropical rainforest in deep soils with dense vegetation (Egboka and Nwankwor, 1985). Gully erosion-induced problems have been discussed by several authors (Tebebu et al., 2010; Tamene and Vlek, 2007). Apart from the negative effects on land, gully erosion has been identified as a major source of sedimentation in wetlands, lakes, streams and rivers.
In tropical regions such as southeastern Nigeria, Igbokwe et al. (2008) reported the occurrence of several gully sites in Southern Nigeria. Some of these gully sites have depths varying from 1m to 150m, widths from 0.4 to 5.6km and length from 0.7 to 2.5km. Most of them lie along a linear zone of weakness and have become a tourist attraction (Onu et al., 2012). An assessment of gully sites by Egboka (2004) and Igbokwe et al. (2008) in Anambra State shows that the State has the highest number of gullies with over seven hundred active gully sites.

Furthermore, gully sites occur in different sizes and magnitudes and some have attended maximum sizes of canyon. Their depths range from 1m for the shallow gullies to about 150m for the deep ones. Where the deep gullies truncate watertable, groundwater flows out as springs and seepage flows with further expansion of the gully. Some of the gullies are isolated while others are inter-connected and display continuous coalescing structures. These structures have been shown to coincide with paleo- and neotectonics events in gully erosion prone-areas of southeastern Nigeria (Egboka et al. 1990). The neotectonics event are associated with recent happenings of landslides and seismic shocks. While, the assessment of hydrogeological characteristics of soils at 1m, 2m and drilled cutting from boreholes at different depths showed that it relates well with the geologic settings and contribute to gully erosion/landslide development in this study.

In Anambra State of Southeast Nigeria, gully erosion is a significant geo-environmental problem ravaging the land with enormous destruction of lives and property. The geographical location and climatic conditions favours gully development and expose over 80 percent of the total land area to rainfall with average precipitation of 1800mm (Iloje, 1981). Rainfall intensity is very high during the rainy season and extreme rainfall increase water level and generates surface runoff and flood that erode and damage the landscape.

A prominent topographic feature on the landscape is the Awka-Orlu escarpment/cuesta with steep scarp slope to the east and gentle dip slope to the west directions. The slopes are characterized by lineament/features of gullies eroded into the subsurface by headwaters of the Imo and Mamu Rivers on the scarp slope. The gentle dip slope is also eroded by the Idemili and Orashi Rivers that flow downslope of the escarpment/cuesta. Mamu River flows westwards into the Anambra River and the Idemili; Orashi Rivers flow westward into the River Niger (Egboka et al., 1985 and 2016; Okoye et al., 2014). Underlying the escarpment is the Imo Shale overlain by the Nanka Sands and partly by Ogwashi-Asaba Formation (Nwajide, 2013). Of these formations, the Nanka Formation is the most affected by gully erosion. Furthermore, the escarpment/cuesta subtends aquifers of various sizes and depths from which groundwater flows out as springs and seepages which produces hydrologically active streams and rivers.

Large area of the landscape has been gullied and many towns and cities are located on the gully erosion-prone areas. A typical case is the gully erosion sites at Agulu, Nanka, Ekwulobia, Umuchu, Oraukwu, Alor, Nnobi, Ideani and Nkpor etc. Gully erosion is very active in these towns as lands and infrastructures have been destroyed and thrown into the gully while others are on the greenbelt of the potential
collapsing soil zones. These areas have suffered severe land devastation and human, animal and plant lives loss with destruction of property.

Available data showed that measures applied to control gully erosion problems have not been very effective as new cases of gullies are developed annually during rainy season. Until now, no realistic solution has been found to the problem (Igbokwe et al., 2008; Ezezika et al., 2011; Okoro et al., 2011; Igwe., 2012, Okoyeh, et al., 2014; Egboka, et al., 2016; Egbueri, et al., 2020). Hence, the need for hydrochemical and geological investigations of gully erosion-prone areas in parts of Anambra State, to determine their vulnerability to gully erosion. The research/study will assess the physicochemical and properties of the soil material in the area for their influence on gully erosion and landslide development.

1.1 Study area and climate

Anambra State lies within longitudes 6° 36' and 7° 21 East and latitudes 5° 38' and 6° 47' North in the South-eastern part of Nigeria. The study area consists of elevated areas and low-lying landscape with valleys. The elevated area forms a low asymmetrical ridge that runs from northwest to southeast with a crest of about 350m above mean sea level. The ridge or escarpment is flanked by steep scarp to the east and gentle dip slopes to the west directions. The area is drained by a network of streams and rivers flowing out from both flanks of the escarpment into the River Niger and Anambra River.

There are two major climatic conditions characterized by rainy and dry season. The rainy season lasts from April to October while the dry season runs from November to March (Inyang., 1975) with a period of extreme coldness and dryness called harmattan running from December to January (Iloeje., 1981). The average annual rainfall is about 1800mm while the average annual temperature is about 26.6°C (Duze and Ojo, 1982). Relative humidity in the area is generally high and ranges between 60% and 95% during the rainy season and falls below 60% during the dry season, thus ensuring the continuous presence of moisture in the air.

The study area is positioned in the Tropical Rainforest Belt of West Africa, characterized by lofty trees with thick undergrowth and lush foliage. However, the exponential rate of anthropogenic activities such as deforestation has given way to sparse vegetation in some areas.

2. Materials And Methods

A total of 40 soil samples were collected with drilled cuttings from on-going boreholes as at the time of this study (Fig. 2). At each gully site, coordinates and elevation were measured using Garmin GPS and recorded. Grainsize analyses were carried out and the data used to plot the particle size distribution curve.
Groundwater samples were collected from boreholes at Agulu, Ukpo, Oko, Ufuma, Awkuzu, Nise, Awka while surface water samples were collected from Idemili River, Odo River, Mamu Rivers, Agulu lake and Amiagba Abatete lake. All water samples were analyzed for their physicochemical parameters to determine their contribution to gully development. The physical parameters determined were pH, total hardness, total dissolved solids and the chemical parameters are calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), iron (Fe$^{2+}$), nitrate (NO$_3^{-}$), sodium (Na$^+$), chloride (Cl$^-$), sulphate (SO$_4^{2-}$), and bicarbonate (HCO$_3^-$). These ionic species were analysed using the atomic absorption spectrophotometer (AAS).

The map of the study area, location of soil samples and the gully profiles were produced using Arc Gis software.

2.1 Data analysis

Graphical and statistical methods were used for data analysis. These methods provide useful information about the soil and its relationship with water movement. Statistical data of water samples were used to plot the piper trilinear diagram for water types identification. The values of the major cations (calcium, magnesium and sodium) and the anions (chloride, sulphate and bicarbonate) in milligram/liter were converted to milliequivalents using the Piper (1944) formula,

$$\text{Milliequivalent/liter} = \left(\frac{\text{Milligram/liter}}{\text{Equivalent}}\right) \times 100$$

3. Result And Discussion

3.1 Regional Relief

The relief of the study area shows a system of highland and lowland within a network of drainage systems. The highland is a topographic expression of the Awka-Orlu escarpment/cuesta with a steep scarp to the east and a gentle dip slope to the west direction and stretches from the north to south in the study area. A major depression extends from east to west across the northwest constitute the idemili river valley, other rivers are Ulasi and Odo in the south west. There is also presence of lakes such as Agulu, Ezu Nawfia and Ezu Amiagba. The wetland occupies the west close to Anambra River and River Niger. These features are represented on the map (Fig:4.1), with the elevated areas shaded with different colours of blue and yellow while the valleys and lowland are shaded brown and the wetland red.

The Idemili River display a dendritic drainage pattern with the main river valley in the central region and its tributaries (streams/river). It is flanked by highland to the east and west directions. The highland area coincides with areas of intensive gully erosions/mass wasting and groundwater discharge zones. At Nri a radial drainage pattern is observed where a hill stands bounded by two extensive depressions of a prototype. One of the gorges, the Enugu-Ukwu-Nimo-Nri depression to the northwest harbors a line of lakes of the Ezu-Nawfia and Ulasi lakes. The second depression line passes down from the Agulu Lake.
Further x-ray using the ArcGIS and digital elevation Model show the relief and gully profiles in parts of the study area which is presented as A-A, B-B and C-C sections (Fig: 4.1).

### 3.3 Gully Profiles

The gully profiles show an undulating landscape, gully features and valleys with channels of stream and rivers. The gully features x-ray as C-C, B-B and A-A profiles show a highland of 320m, 210 and 190m respectively with depths of 150m, 90m and 75m within a distance of 0-9000m, 0-7500m and 0-13250 respectively (Fig: 4.2).

The topographic expression maintains a high surface and subsurface hydraulic gradient which influence groundwater recharge and discharge (Egboka and Nwankwor (1985); Onwuemesi and Egboka, (1991). Groundwater discharge and surface water flow contributes immensely to the development of gullies. Seepage fluxes produce hydrologically active streams and rivers that form agent of erosion. Many of the erosion surfaces represent headwater of streams and rivers emanating from groundwater discharge zones. Their close contact with the surface water facilitates gullying processes in the study area. A typical case is the Nanka gully site where gullying activity is intensive. The site marks the headwater of Mamu River which is the widest channel within the C-C section. Flowing water erodes soil materials and create instability in the loose and unconsolidated sediments. Groundwater flow and possibly water level rise may lead to reduction in shear strength and subsequent failure of the soil material where it is weak and vulnerable to erosion. Similar development occurs in other areas captured by A-A and B-B cross sections of the gully profiles (Fig. 4.2).

The highlands represent areas of intense gully activities and form part of the Awka-Orlu escarpment/cuesta which is the main topographical ridge/cuesta. The cuesta runs from north to south flanked by a steep slope to the east and a gentle dip slope to the west directions with series of erosional surfaces and gully lineaments. So, gullies profiles C-C is taken along the steep slope while B-B and A-A are from the gentle dip slope. Their orientation shows that the slope controls the movement of groundwater in the east and west directions. Groundwater originates as rain water that infiltrates through the soil into flow systems in the underlying geologic materials from where it flows out as springs and seepages into streams and rivers.

### 3.3 Hydrogeochemistry

The result of the hydrogeochemistry and their relevance to gully erosion and landslides development is presented
The Hydrogeochemistry reveals the physical and chemical constituents of the surface water and groundwater. The pH values for surface water and groundwater range from 5.53 to 6.58 mg/l with average value of 5.99 and 5.48 to 6.4 mg/l with average value of 6.31 mg/l respectively, indicating slightly acidic water when compared with World Health Organization Standard (2004) (Table:1). The slightly acidic nature of the water may be due to carbon dioxide dissolved in rain water and decayed organic matter in the soil (Hem, 1985). This may lead to the decomposition of the cementing material of the soil and loosening of the grains to erosion. Such slightly-acidic water facilitates the decomposition of the cementing material in soil (MacDonald et al.2005). Soil with decomposed cementing materials is susceptible to erosion.

The chemical constituents include mobile alkalis of magnesium, calcium, sodium, chloride, iron, and compounds of bicarbonate (\(HCO_3^-\)), sulphate (\(SO_4^{2-}\)), and nitrate (\(NO_3^-\)) ions. The surface water analyzed contain; magnesium (Mg\(^{2+}\)) values range from 0.09 to 3.12 mg/l with average value of 1.56 mg/l, calcium (Ca\(^{2+}\)) values range from 0.83 to 4.07 mg/l with average value of 3.40 mg/l, sodium (Na\(^+\)) values range from 0.02 to 4.68 mg/l with average values of 2.27 mg/l, chloride (Cl\(^-\)) values range from 3.78 to 35.00 mg/l with average value of 22.28 mg/l, iron values range from 0.03 to 0.78 mg/l with average values of 0.38 and for groundwater magnesium values range from 0.69 to 5.00 mg/l with average values of 2.97 mg/l, calcium 2.4 mg/l to 8.0 mg/l with average value of 3.50, sodium 0.3 to 4.15 mg/l with average

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Surface water samples</th>
<th>Groundwater samples</th>
<th>WHO (2012) Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5.53–6.58</td>
<td>5.99</td>
<td>5.58–6.4</td>
</tr>
<tr>
<td>Total hardness</td>
<td>10–52</td>
<td>33.5</td>
<td>13–70</td>
</tr>
<tr>
<td>TDS</td>
<td>16–150</td>
<td>63.16</td>
<td>22.3–140</td>
</tr>
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<td>37.85</td>
<td>8.0–50</td>
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<tr>
<td>Sulphate mg/l</td>
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<td>3.81</td>
<td>&lt;1–5.0</td>
</tr>
<tr>
<td>Chloride mg/l</td>
<td>3.78-35</td>
<td>22.28</td>
<td>4.2–40</td>
</tr>
<tr>
<td>Nitrate mg/l</td>
<td>0.47–7.49</td>
<td>4.73</td>
<td>4.95–23.9</td>
</tr>
<tr>
<td>Magnesium ppm</td>
<td>0.09–3.12</td>
<td>1.56</td>
<td>0.69-5.0</td>
</tr>
<tr>
<td>Calcium ppm</td>
<td>0.83–4.07</td>
<td>3.40</td>
<td>2.4-8.0</td>
</tr>
<tr>
<td>Iron ppm</td>
<td>0.03–0.78</td>
<td>0.38</td>
<td>&lt;0.1–0.26</td>
</tr>
<tr>
<td>Sodium ppm</td>
<td>0.02–4.680</td>
<td>2.27</td>
<td>0.3–4.15</td>
</tr>
</tbody>
</table>
value of 2.6mg/l, chloride 4.20 to 40.00mg/l with average value of 15.09mg/l iron < 0.1mg/l to 0.26mg/l with average value of 0.23mg/l. Magnesium and calcium ions are easily exchanged for sodium ion in the soil and water movement through the soil can leach the dissolved minerals. In addition, these constituents reflect the solvent potential action of the water to dissolve the minerals and leaching of soluble minerals in the soil. It shows that precipitated water can facilitate the dissolution of minerals and loosening of soil grains.

The surface water and groundwater also contain ionic compounds of bicarbonate (HCO$_3^-$), sulphate (SO$_4^{2-}$), and nitrate (NO$_3^-$) (Table: 4.3). The result of surface water reveal bicarbonate (HCO$_3^-$) values range from 3.14 to 65.00mg/l with average value of 37.85mg/l, nitrate values range from 0.47 to 7.49mg/l with average value of 4.73mg/l and sulphate values range from 2.00mg/l to 4.53mg/l with average value of 3.81mg/l; and groundwater bicarbonate 8.00 to 50.00mg/l with average values of 25.46mg/l, nitrate 4.95 to 23.90mg/l with average value of 11.61mg/l which indicates input from agricultural activities, sulphate < 1mg/l to 5.0mg/l with average value of 8.49mg/l. The presence of sulphate indicates a reducing condition and consequently a quasi-anaerobic environment. Oxidation-reduction (redox) reactions are possibly occurring along the water flow system through complex geochemical activity. Water as a solvent is capable of dissolving and interacting with organic and inorganic components/minerals that make up the rock matrix. These processes contribute to soil disaggregation, soils erosion and destruction of engineering structures built to control gully erosion.

The Total Dissolved Solid (TDS) values for the surface water from16 to150mg/l with average value of 63.16mg/ and for groundwater, range 22.30 to 140mg/l with average value of 50.90mg/l respectively (Table: 4.3). The bulk of the dissolved solid maybe attributed to chemical reactions from oxidation-reduction and ion exchange reactions in the soil. The ion exchange reaction shows the cation exchange potential of some minerals especially of the clay family when water interacts with the soil. Clay minerals have high cation exchange capacity and may exert considerable influence on the concentration of different cations in the water associated with them (Hem, 1985). Exchange of calcium for sodium increases the sodium level and also the total dissolved solid in groundwater (Freeze and Cheery, 1979 and Favara et al., 2001). The distribution of the physicochemical constituents is represented on the bar charts (Figs: 4.12–4.13).

The original meteoric water which enters the ground has been altered through processes of weathering and erosion accompanied by mineral dissolution. Generally, the presence of the physical and chemical constituents in the water samples is attributed to variation in the mineralogical and chemical composition of the rocks and the difference in geochemical processes. Results of hydrochemical analyses of the surface water and groundwater are presented in (A.2 and A.3). It is also apparent that the study area is influenced by the variability in the geologic materials.

### 3.4 Water type characterization

Generally, the hydrogeochemistry of the water is attributed to variation in the mineralogical and chemical composition of the rocks and the difference in geochemical processes of the study area.
Specific ionic species of magnesium (Mg$^{2+}$), calcium (Ca$^{2+}$), sodium (Na$^+$), chloride (Cl$^-$), bicarbonate (HCO$_3^-$) and sulphate (SO$_4^{2-}$), were employed to plot the piper trilinear diagram for both surface water and groundwater samples (Fig: 4.14 and Fig: 4.15). The values of calcium (Ca$^{2+}$), magnesium (Mg$^{2+}$), sodium (Na$^+$) chloride (Cl$^-$), bicarbonate (HCO$_3^-$) and sulphate (SO$_4^{2-}$) in mg/l were converted to milliequivalent and the converted values in meq/l presented in (A.4 and A.5). The values of the cations and anions were used to plot the piper trilinear diagram from which sodium bicarbonate water type (Na-HCO$_3$) was identified. Then, using Back and Hanshaw (1965) subdivision of piper trilinear diagram to determine the percentage hydrochemical composition, the main water type identified in surface water and groundwater is the one in which alkalis exceed alkaline earth elements by 100% and weak acid (CO$_3^-$ + HCO$_3^-$) exceed strong acid (SO$_4^{2-}$ + Cl$^-$) by 100%, sodium bicarbonate type 100% and 57%. Mixed type (No cation-anion pairs exceed 50%) occur with 43% in groundwater and none in surface water (Table: 4.4). The identified water types constitute distinct zones with anions and cations concentrations within defined composition called hydrochemical facies. The water chemistry is controlled by sodium bicarbonate water and mixed type. It can be concluded that the predominant water type is sodium bicarbonate (NaHCO$_3$). The high percentage of sodium water suggests possible ion exchange reaction and mineral dissolution. These processes may lead to loosening of the soil grains and the disaggregation of the host rocks.

The geochemical processes operating within the hydrogeological framework and the water pattern is reflected in the facies composition. The major geologic deposits in the study area are the Nanka Sand and Imo Shale. Nanka sand is characterized by poorly consolidated to unconsolidated sand. The sand is severely dissected in places and specks of micas, grains of quartz and other minerals gives a reflective/shine characteristic with light. This dissection gives rise to dangerous spots and a badland topography withs negative relief feature of variable magnitudes.
Table 2
Characterisation of surface water and groundwater of the study area based on piper trilinear diagram using Back and Hanshaw, 1965 subdivision.

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

3.5 Lithologic Characteristics

The sedimentary sequence as observed from drilled borehole and geophysical model of vertical electrical soundings show a succession of lateritic topsoil, clay, shale, silt, sand, sandstone, gravel and lignite in places. These units give insight into the geological and hydrogeological settings of the study area.

At locations of Ringroad(Awka)–Nwagu(Agulu)–Amihe(Umuchu)–Obiuno(Igboukwu) axis on the steep scarp slope, the lithologic sections from drilled borehole shows layers of lateritic top soil, shale/clay, shaley sand, shale and sand with thickness values range from 23.0–53.0m, 0–7.50m, 16.90–25.80m, 13.80–30m, 175m, and 70–580m, respectively. Lignite was observed at Igbokwu at a depth of 670m (Fig: 4.3).

Similarly, lithologic sections at Oroma Etiti–Obolo (Oratite)–Otolo (Nnewi)–Obeledu axis shows layers of clay, silt, sand and gravel with thickness values range from 10-40m, 3-100m, 5-50m, and 20-25m respectively with lignite in parts (Fig: 4.4).

Geophysical model/geo-sections from vertical electrical soundings at Oranto(Ukpo)– Eneagu (Abagana)–Ifite(Enugu Agidi)–Omor axis shows layers of lateritic top soil,shale, sandy clay, silty sand, shaley sand and sandstone with thickness values range from 0–4.55, 4.18–45.30m, 5.82–30, 0.8.66, 2.8–20m, 0-5m, respectively (Fig: 4.5).
Geophysical models/geo-sections from vertical electrical soundings also at Umunanbor (Alor)-Amankpume-Nsukwu (Abatete) –Umudim (Oraukwu) – Eke(Adazi Nnukwu) – (Agulu) axis shows layer of lateritic top soil, shale, shaley/clayey sand, sand, and sandstone with thickness values range 0–2m, 3–6m, 2–38m, 17–40, 3–108m respectively(Fig. 4.6). These sections are similar to that of the Niger Delta Basin as seen from the geological deposits.

From the lithologic sections, Awka–Agulu–Umuchu–Igbokwu axis, Oroma (Etiti)–Obolo (Orate)–Otolo(Nnewi)–Obeledu axis, Umunanbor(Alor)-Amankpume(Nsukwu Abatete)–Umudim(Oraukwu)–Adazi Nnukwu–Agulu axis and Eneagu Abagana-Oranto-Ukpor-Omor-Ite-Enugu Agidi axis host a top substratum made up of red clayey sand/laterite underlain by a thick sand unit with some amount of gravel. The sand and sandstone layers are potential material for groundwater resources and interbedded with shale and clay. These units form a multi-aquifer system consisting of confined and unconfined aquifers.

The geology of the study area is predominantly sand with good hydrogeological settings that form part of the Nanka Sand Formation. Geologically, the Nanka has been described as loose and poorly consolidated sand (Nwajide, 2013). The loose sand nature makes it susceptible to erosion and account for the development of lineaments of gully on the steep scarp slope and gentle dip slope of the Awka-Orlu escarpment/cuesta. Deep gully lineament may truncate watertable and groundwater flows as effluent seepages that further expand the gully. Seepage action dislodges the soil grain and erodes the subsurface material. This may result to instability with hydrogeological consequences that trigger off gully erosion and landslide.

4. Discussion

The physiochemical parameters reflect the physical and dissolved chemical species in the water from geochemical reactions and leached chemical specie from the soil. These dissolved chemical species form the bulk of the total dissolved solids. The alterations of the chemical and mineral composition of the soil may results to changes of the physical condition of the soil. Thus, the loss of chemical elements is accomplished by the increase in porosity and pore spaces (Frolova et al., 2001). Moreover, the water chemistry revealed Na-HCO$_3$ water type which is a reflection of precipitation and ion exchange reaction/mineral dissolution that may result to lose of soil binding materials. Such soils are prone to dispersion and vulnerable to erosion.

Geologically, the soil consists of layered sequence of lateritic topsoil, sand, sandstone, shale with intercalation of clay and siltstone. These geologic units enhance the groundwater resources potential of the study area. However, their good hydrogeological characteristics produce negative geotechnical impacts on the environment. Particularly important among these is the erosion of the soil which accounts for the widespread development of gully type erosion. A survey of the study area shows that it is endowed with abundant surface water and groundwater resources.
The rocks matrix is dissolved by surface processes of weathering and erosion. These processes are accompanied by the release of soluble minerals of magnesium, calcium, sodium, chloride, iron, bicarbonates, nitrate and sulphate ions when water comes in contact with the rocks or infiltrates into the subsurface. Precipitation that falls to the ground is enriched with minerals from the rocks and flows as runoff to streams and rivers, part of the water infiltrates into the ground. Infiltrating water becomes enriched with dissolved chemical solutes released from the rocks forming agent of erosion. As the water moves downward into groundwater further reaction releases dissolved chemical species. Minerals dissolution are due to ion exchange and oxidation reactions which gives the soil its reddish-brown coloration. The mineralized water becomes highly enriched in dissolved solutes which form the bulk of the total dissolved solids These may lead to lose of cementing material and disaggregation of the soil. Moreover, the hydrochemical facies reveal sodium bicarbonate (Na-HCO₃) water type. The predominance of sodium bicarbonate (Na-HCO) water is due to ion exchange reaction and mineral dissolution. Thus, the loss of chemical elements is accomplished by increase in porosity and pore spaces (Frolova et al., 2001).

The distribution and density of gully erosion sites show that gullies in the state are more concentrated in the unconsolidated sand–dominated Nanka Formation that occupied the central region. The Formation exhibits typical hydrogeological properties and geotechnical characteristics that are favorable to the initiation and development of soil erosion and gullies. Sediments in the central region of the study area are porous and permeable with high hydraulic conductivity. The hydraulic conductivity distribution is shown on the map (Fig. 4.17 and Fig: 4.18). In the studies of Egboka and Okpoko (1984) and Okoyeh et al. (2014), high porosity, hydraulic conductivity, transmissivity and the dominance of loose, friable, poorly cemented and highly permeable sands makes the formation vulnerable to erosion. The hydraulic properties of the soil indicate high values which would advance the growth and enlargement of gully erosion where the overburden laterized topsoil has been eroded.

Depths to watertable data are obtained from the geologic/lithologic sections at Nwagu Agulu, Amihe Umuchu, Umunambor Alor, Amankpume Nsukwu, Abatete, Umudim Oraukwu, Adazi Nnukwu, Ukpor, Otolo Nnewi, Obolo Oratite to be 110m, 170m, 130m, 120m, 130m, 132m, 40m, 40m, and 30m depths respectively. Towns such as Agulu and Umuchu on the highland have high watertable and in order with the Ameki Formation/Nanka Sand which dips gently away from the water divide that runs from north to south of the area (Egboka et al., 1990). Groundwater consequently flows southwest and east away from the groundwater divide. Such flow pattern could be responsible for the gully ravaging the land and formation of lineaments on the topographic slope.

Water wetting surfaces were observed at Nimo outcrop site and Amada Oraukwu from which water concentrates into channel. The concentrations have led to the development of major gullies with new cases especially during the rainy season. Furthermore, wetting surfaces indicates water levels rise which may generates pore water pressure and seepage flow in the subsurface. This is attributed to the high porosity and permeability of the medium to coarse grained soil. Fluidization and quicksand conditions may develop in locations where the groundwater flow path is directed upwards. Upward increase in water level and seepage flow are possible especially where groundwater is deep below the surface in the study.
area. At localities such as at Nanka and Oraukwu such quicksand conditions and seepage flow are common features.

The values of the bulk density and compaction density with its optimum water content shows that the density of the soil is relatively low, poorly consolidated and therefore prone to erosion. This is in line with the observation of (Hudec et al., 2006). The low densities might also be a reflective of the loose and poor bonding condition that exists between the soil particles. A combination of the low density and the moisture content shows that the soil is not saturated and will allow infiltration of water which is a detriment to slope stability. Infiltrating water may be truncated by clay layer resulting to the accumulation of water on the sand-clay interface and subsequent lubrication of the clay surface.

The soil shows some degree of plasticity despite the sandy nature of the soil. This accounts for the drying of the soil and formation of tension and desiccation cracks on the land surface. These cracks are transferred into the sand material where they serve as pathways for water penetration into deeper depths. Infiltrating water may be truncated by clay layer resulting to the accumulation of water on the sand-clay interface and subsequent lubrication of the clay surface. In addition, the clay content of the soil material are capable of absorbing water and expanding which is a detriment to slope stability conditions and hence gully erosion and landslides problems.

This hydrophilic tendency of the soil samples suggests the presence of expansive clay which also has adverse effect on slope stability. As stated by Richter (1976), cracks in rocks are produced when local stresses exceed the shear strength of the material. The mechanical stressed rock develops grain boundaries that are continuous along boundaries of several grains and within the mineral grain producing planes of weakness in the soil that can be trigged off by slight shock. These are precursors to development of gullies and landslides.

### 4.12 Field Observations and Impacts of Gully Erosion and Landslides

The gullies were observed to cause damage to roads, buildings, farmlands, springs, streams as well as residential homes. Life and property are regularly lost with people displaced from their homes and buildings abandoned. Poorly constructed roads have become major flood channels and natural flow channels are diverted to increase the eroding force of their neighboring stream channel. Towns, communities and families have been separated by gully from one another. Basic utilities of water supplies, electricity and telephone services have been destroyed. Churches, markets/commercial centers/industries, schools etc. have been lost or damaged by advancing gullies and landslides. Sensitive drainage areas, wetlands, agricultural lands and flood plains encroach by land developers and modern buildings have occupied groundwater recharge areas.

A conceptual model of gully erosion is presented below. Gully begins as rill and gradually incised the substratum deeper, lengthened by head wear and expanded through mass movement (Fig: 4.19).

### 5. Images Gully Sites
Some of the gully sites images were captured during the course of the fieldwork which express the nature and extent of gully erosion problems in the study area (Plates 1–6)

**Conclusion**

Based on the research findings, the following conclusions are made:

The study area is characterized by numerous surface water bodies and groundwater systems which influence the development and expansion of gullies. The pH of the surface water and groundwater is slightly acidic which affects the decomposition of the cementing material in the rock. Such alteration will lead to soil disaggregation, loosening of soil grains and hence, erodibility of the soil. The permeability soil suggests high seepage fluxes and pore water pressure. Upward flow is possible where watertable is deep below the surface resulting in quicksand conditions. These processes reduce the shear strength of the soils and account for development of gully and increase of incipient gullies.

Cross section maps of the study area show the gully profiles and the encroachment of gullies on the available land space may turn the entire landmass to a waste land. This fear has sent many people away from their homeland into neighboring towns and States. The integrated hydrochemical and geological evaluation of gully erosion prone area show that soils in Anambra state is vulnerable to gully erosion.

**Declarations**

**Authors contribution**

All authors contributed to the study the study conception and design. Material preparation, data collection and analysis were prepared by Stella Nwaife Chibuzor and Boniface E. Egboka. The first draft of the manuscript was written by Stella Nwaife Chibuzor and all other authors comment on the previous version of the manuscript. All authors read and give their final approval of the manuscript.

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**References**


Figures
Figure 1

Location Map of the Study Area.
Figure 2

Locations of gully erosion sites in the study area.

Figure 3
Fig. 4.1: Map Showing Relief and Gully Sections in Anambra State

Figure 4

Fig. 3.2: Gully Profiles of some Gully-prone Areas in Anambra State. Sections A-A (Oraukwu - Ojoto), B-B (Nnobi-Nnewi) and C-C (Agulu-Ekwulobia)
Figure 5

Fig. 5 Bar chart for the average values of physiochemical parameters and their distribution in surface water samples.
Figure 6

**Fig. 6** Bar chart for the average values of physicochemical parameters and their distribution in groundwater samples
Figure 7

Fig. 7. Piper diagram of surface water hydrochemical facie
Figure 8

Fig. 8. Piper diagram of groundwater hydrochemical facies.
Figure 9

Fig. 4.17: Contour map of hydraulic conductivity distribution at 1 meter depth
Figure 10

Fig. 4.18: Contour map of hydraulic conductivity distribution at 2meters depth
**Figure 11**

Fig 4.19: Model of the gullying processes applicable to Awka-Orlu cuesta (modify from geological survey of Nigeria)

**Figure 12**

Legend not included with this version