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# An escalating environmental effect of erosion threat in Abia State - Nigeria

Nelson Ikechukwu Okoroigwe [1, *], Victor Uchechukwu Nkemdirim [2], Ugochukwu Udonna Okonkwo [3], Opeyemi Adebola Ojo [4] and Rachel Okere [5]

[1] *American Association of Geographers, Washington, USA.*
[2] *Department of Geography, Faculty of Engineering and Environmental Studies, Abia State University, Uturu, Nigeria.*
[3] *Department of Geography and GIS; College of Arts and Sciences; Southern Illinois University, Edwardsville, USA.*
[3]*Department of Computer Management & Information Systems, School of Business; Southern Illinois University, Edwardsville, USA.*
[4] *Department of Geography, College of Liberal Arts (COLA), Marshall University, Huntington, WV, USA.*
[5] *Federal Competition and Consumer Protection Commission, Asokoro, Abuja-Nigeria.*

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## Abstract

One of the most striking methodological developments in geography during the last two decades is concern with soil erosion. This study of geographic space is part of a more general trend in modern geography, which has been termed the physical revolution, and which followed the quantitative revolution of solving and analyzing soil erosion problems.

Very few models have the potential to predict ephemeral gully erosion sites, for example, CREAM, WEPP, and EGEM. The Ephemeral Gully Erosion Model (EGEM), A method for computing ephemeral gully erosion was developed under the direction of Dr. John Laflen, USDA, Agricultural Research Service (ARS), to predict soil loss by ephemeral gully erosion.

Erosion of farm fields due to concentrated flow is severe in many parts of Isuikwuota. Soil erosion prediction methods currently in use include the Universal Soil Loss Equation (USLE) and Revised USLE. These methods account for sheet and rill erosion and not for erosion from concentrated flow. The term “ephemeral gully” has been applied to a concentrated flow channel larger than a rill routinely obliterated due to tillage operations. An estimation technique for ephemeral gully erosion is needed both to quantify the problem and analyze alternatives for the solution of the problem. With renewed interest in modeling ephemeral gully erosion in agricultural areas, the EGEM model could be the basis for an improved model with stronger physically based algorithms, wider geographical applicability, and watershed application using GIS.

**Keywords:** Ephemeral gully; Soil erosion; Erodibility; Modeling; Sediment transport

## 1. Introduction

Erosion menace is today a very important issue in human health; however, it has today engrossed the general concern of professionals in finding a lasting solution to this environmental threat called erosion. At present, erosion is one of the most important ecological problems threatening the world, almost exclusively in the southeastern part of Nigeria, which is fully possessed by erosion delinquents. Erosion has amplified pollution and sedimentation in streams and rivers, also clogging the watercourses. Soil erosion is a public term used to either explain soil degradation or the physical removal of soil (Handley, 2011). Soil erosion is the detachment and transportation of soil particles by agents such as wind or water (Handley, 2011, Toy et al., 2002). This term can apply easily to gullies because soil is removed

* Corresponding author: Nelson Ikechukwu Okoroigwe

and is usually caused by some sort of soil degradation. However, most classify the type of erosion by the erosive agent, wind or water, which causes the erosion. Gupta and Swati considered Soil to mankind as a basic natural resource. Also the World Wildlife fund (WWF) defined Soil as the earths delicate skin that anchors all life on Earth. It comprised of innumerable species that craft a dynamic and multifaceted ecosystem and is among the most valuable resources to humans. Soil erosion is one form of soil degradation, low organic matter, and loss of soil structure, poor internal drainage, salinization, and soil acidity problems.

Erosion is a widespread environmental issue that poses significant threats to agricultural productivity and water quality worldwide. Globally, approximately 1.1 billion hectares of land had been lost to soil erosion by 2005, with an annual loss of three million hectares of agricultural land (Pathak et al., 2005; Dube, 2011). In Europe, 16% of the landmass is affected by erosion, particularly in Mediterranean regions such as Spain and Portugal (Rompaey et al, 2004). Africa, particularly Sub-Saharan Africa, is among the worst affected regions, with an estimated 65% of its land impacted by erosion (Dejene & Malo, 2011). Zimbabwe, for instance, has suffered extensive land degradation due to severe gully erosion, resulting in the loss of millions of hectares of farmland (Anderson et al., 1993; Dube, 2011).

Currently, gully erosion is not accounted for in soil-loss assessment programs, but its contribution and importance to total soil losses have been recognized for a long time (Handley, 2011). Crafting a comprehensive protection measure for soil erosion requires accurate data on erosion sites, rates, their spatial extents, vulnerable areas, current causes, relatives' contributions from different sources, and likely impacts on land. However, the identified deficiencies in soil erosion assessment methods are rectified in the soil erosion model.

There are dozens of erosion prediction models. Some models focus on long-term (natural or geological) erosion as a component of landscape evolution, while many others of the erosion models were developed to quantify the effects of accelerated soil erosion, i.e., soil erosion as influenced by human activity. Most erosion models consider only soil erosion by water, while a few others aim to predict wind erosion. Models that consider tillage erosion rare, and so also are models that consider gully erosion very rare. The present erosion models are aimed at agricultural landscapes rather than naturally vegetated areas (such as rangeland or forests).

Most of these soil erosion models predict average rates (often an annual average rate) of soil loss from an area such as a plot, a field, or a catchment/watershed under various land management techniques. Some erosion models are purely statistical, others more mechanistic (or physically based). Two of the more widely used soil erosion models are the Revised Universal Soil Loss Equation (RUSLE) and the Water Erosion Prediction Project erosion model (WEPP), and much of the mine land erosion literature is solely focused on fitting or improving RUSLE parameters. Few erosion models consider gully erosion, mostly due to difficulties in modeling these large erosional features.

In Nigeria, gully erosion has remained a persistent environmental challenge, particularly in the southeastern region. Ofomata (1965) noted that the problem has been a significant concern for decades. Reports from July 2017 on Channels Television highlighted the devastating impact of gully erosion in several states, including Abia, Akwa Ibom, Kogi, Anambra, and Oyo. Although efforts such as the Nigeria Erosion and Watershed Management Project (NEWMAP) have been initiated to mitigate these effects, erosion continues to cause severe damage to infrastructure, farmlands, and communities. Recent interventions, such as a ₦1.1 billion project in Kano and erosion control measures in Ideato South, Imo State, aim to address land degradation and enhance water conservation.

Isuikwuato Local Government Area in Abia State is particularly vulnerable to gully erosion due to its high-intensity rainfall and steep topography. The erosion has led to significant losses of topsoil, reduced agricultural productivity, and the destruction of roads, properties, and businesses. For instance, records from 2008 show that key roads, including sections of Uturu-Isuikwuato road and Mgbelu Umunnekwu-Ovim road, suffered severe erosion damage. Entire communities have been cut off, and economic activities, including businesses and schools, have been abandoned. Investments such as Pelly Petrol Station and Commercial Secondary School in Mgbelu Umunnekwu have closed due to erosion, and even burial sites are at risk of being washed away. The primary aim of this study is to develop a geo-database solution for gully erosion using erosion modeling techniques in Isuikwuato LGA. The specific objectives are to analyze the physio-chemical properties of soil in the study area, simulate the relationship between rainfall and runoff using a digital elevation model, model total soil loss in selected gully erosion sites and develop a GIS-based geo-database for sustainable erosion management.

The deficiencies of soil erosion assessment method bring to the need for Geographic Information System (GIS) and Satellite Remote Sensing platform (Shrestha 2004, Ogbonna 2009). From this point of view a sequential series of aerial photographs can be of great help in assessing ephemeral gully erosion rates, as they permit research to be extended in space and time. Several researchers have already used aerial photos to assess soil erosion. Morgan et al. (1980), Morgan and Napela (1982) and Stephens et al. (1985) used high-altitude aerial photos (scale 1:60 000 and 1:120 000) in conjunction with the USLE and a computerized land information system to identify areas prone to erosion. Patton and Schumm (1975) determined gully positions from aerial photographs (scale 1:12 000) and plotted them on topographic maps in order to establish a relation between the drainage-basin area and the critical slope for entrenchment. Vandaele et al. (1996a) continued the work of Patton and Schumm, but tried to assess erosion volumes based on aerial photo data (scale: 1:15 000 to 1:21 000; Vandaele et al. 1996).

This research will use a suitable erosion model to analyze erosion glitches and assess their impact on the landscape. Comparison of the various attributes of the study area constitutes an enabling dataset for evaluating the impact of soil erosion. Interactive thematic maps are created through this process. These maps include soil, land capability, relief, vegetation, land use, geology, geomorphology, and unsupervised Land cover classification.

## 2. Material and methods

### 2.1. Study Area

Isuikwuato is a protuberant community within the Igbo ethnic group, and is located in Isuikwuato Local Government Area, of Abia State, in southeastern Nigeria. It lies in the map of the federal republic of Nigeria at latitude 5°40’26.137’’N and 5°52’11.297’’N and longitude 7°22’59.36’’E and 7°32’ 13.998 ’’East of the Greenwich Meridian. According to the 2016 National population census projection, it has a population of about one hundred and forty-five thousand, three hundred and forty-one (145,341), and the local government area measures about one thousand, five hundred and twenty eight square kilometers (1,5285sqkm) [special report, Isuikwuato movement forum].. Upon the creation of Abia State on August 27, 1991, Isuikwuato became one of the 17 local governments that were created with its headquarters at Mbalano. It is bordered in the north by It is bounded in the north by Umu-Nneochi L.G.A, to the south by Umuahia North, and to the east by Bende L.G.A. Isuikwuato is blessed with many natural resources such as kaolin and iron ore, and cash crops including cassava, yam and palm oil. Isuikwuato is also the home to Abia State University, Uturu.

The rainy season in the area commences in March and ends in October. The annual duration and intensity ranges between 2200mm and 2500mm as shown in figure 4b and last for an average of eight months. The mean daily temperature ranges from 28°C to 35° C, while mean daily temperature ranges from 28°C to 35°C, while mean daily minimum temperature ranges between 19c and 24°C. Annual range is between 22°C and 27°C. The highest temperature of the place occurs before the rains and the lowest occur at the peak of the rainy season as shown in the temperature graph in figure 4. The average relative humidity corresponds fairly to the distribution of rain throughout the year. The humidity is about 60-80% with an average pressure about 1018, 77mb [creative humidity]. The area receives abundant and constant isolation.

### 2.2. Geological Formation

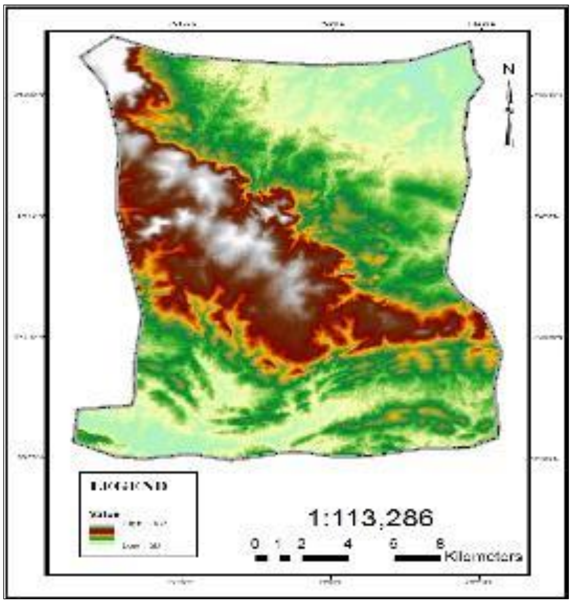


**Figure 1** Soil map of the study area

The rock system and geological history of this area are due to events that took place between Mesozoic and Cenozoic eras respectively. Her structure is divided into three namely, Upper coal measure, False-bedded sandstones, and lower coal measure. The upper coal measure formation is the largest geological formation in this region. It comprises mainly of coarse grains, alternating sediments of grey sands, dark shale which contains sands of impure coal in place of vertical horizon (Nwilo et al, 2011).

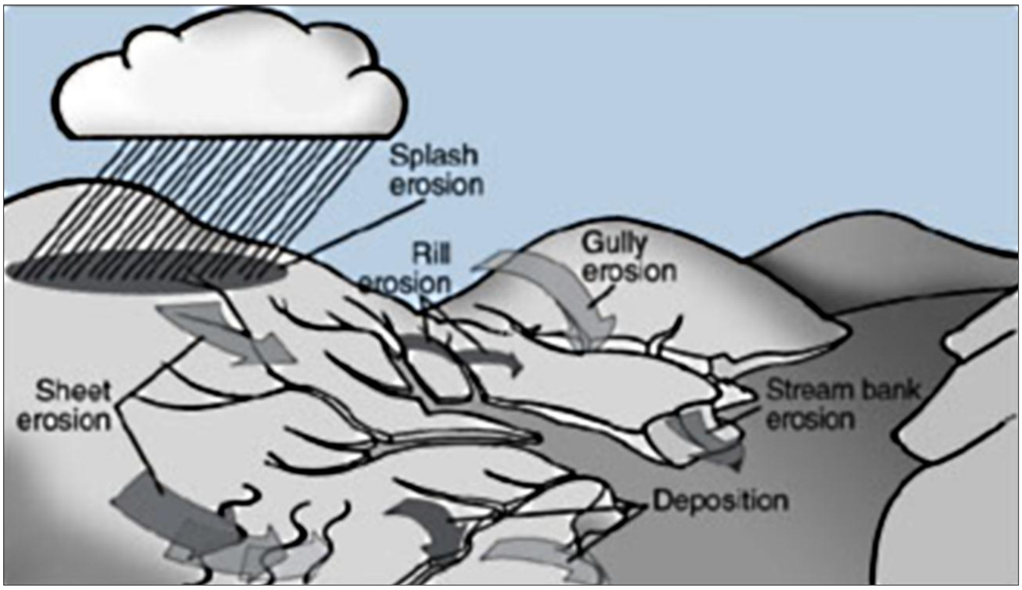


**Figure 2** Image of different forms of erosion (Broz et al. 2003)

**Table 1** Erosion and Soil Erosion Models

| | **Model** | **Source** |
|---|---|---|
| USLE | Universal Soil Loss Equation | Wischmeier & Smith, 1978 |
| RUSLE | Revised USLE | Renard et al., 1994 |
| dUSLE | Differentiated USLE | Flacke et al., 1990 |
| CREAMS | Chemical runoff and erosion from agriculture management systems | Knisel, 1980 |
| ANSWERS | Areal Nonpoint Source Watershed Environment Response System | Beasley & Huggins, 1982 |
| WEPP | Water Erosion Prediction Project | Nearing et al., 1989 |
| OPUS | Advanced simulation model for nonpoint source pollution transport | Ferreira & Smith, 1992 |
| EROSION2D | Erosion- 2D | Schmidt, 1991 |
| PEPP | Process-oriented erosion prognosis program | Schramm, 1994 |
| KINEROS | Kinematic Erosion Simulation | Woolhiser et al., 1990 |
| EUROSEM | European Soil Erosion Model | Morgan et al., 1991 |
| LISEM | Limburg Soil Erosion Model | De Roo et al., 1994 |

This study relies on both primary and secondary data sources covering a period of 24 years, from 1984 to 2008, with a predictive period extending from 2008 to 2018. The primary data was collected through field surveys utilizing a Global Positioning System (GPS) to acquire geo-referenced points, measure heights above sea level, and delineate affected areas. Additionally, high-resolution digital images of the study sites were captured to provide visual documentation of erosion features. The secondary data sources included satellite imagery, topographic maps, and meteorological records.

Landsat TM satellite images of the study area, obtained from the National Centre for Remote Sensing in Jos, provided detailed spatial data, while historical maps, such as the Imo Atlas designed by G&G Planital in 1984, were retrieved from the Ministry of Urban Planning in Owerri, Imo State. Additional geospatial data were sourced from Axion 3D World Atlas, produced by Axion Spatial Imaging Ltd., USA. Climate data, including rainfall, temperature, and evapotranspiration records, were obtained from the National Root Crop Research Institute (NRCRI) in Umudike to assess the climatic impact on erosion processes.

### 2.3. Data Collection and Processing

GPS technology was employed for geospatial data collection to ensure accurate spatial analysis. The study utilized a Garmin 12 XL handheld GPS receiver, which was chosen for its portability and ease of use in field conditions. This GPS device has the capacity to store up to 500 waypoints and operates using the Minna datum, aligning with the Nigerian coordinate system. The device was configured to receive signals from up to 12 active satellites, ensuring precise geolocation of erosion sites. The data acquisition process involved turning on the GPS receiver and waiting for stable satellite signals. The "Mark" key was used to create waypoints, which were then renamed appropriately, such as "Isuikwuato Erosion Site." The latitude, longitude, and elevation of each erosion site were recorded in a field notebook for subsequent analysis. These procedures were repeated at all identified erosion points to establish a comprehensive geospatial dataset. A digitizer was used to convert hardcopy maps into digital vector data to complement the GPS data. A digitizing tablet, equipped with a cursor (puck), enabled precise tracing of map features, which were then stored in digital format. Additionally, an AO+ scanner was employed to capture raster data from topographic maps. The scanned maps were converted into high-resolution digital images and later processed for geospatial analysis.

### 2.4. Geospatial Data Processing

The scanned maps were imported into ILWIS 3.3, a Geographic Information System (GIS) software, to facilitate spatial analysis. The coordinate system was set to the Minna datum with a Universal Transverse Mercator (UTM) projection to ensure geospatial accuracy. Georeferencing was performed by identifying tie points on the raster map and matching them with their corresponding real-world coordinates. Once the maps were georeferenced, vector layers representing features such as rivers, land use, and erosion sites were digitized.

A Digital Elevation Model (DEM) was generated by interpolating contour lines from a 1:50,000 scale topographic map. This DEM provided critical information on terrain elevation, which was essential for analyzing slope gradients and erosion susceptibility. The DEM was further processed using a shadow filter to enhance visualization and create three-dimensional representations of the study area. The generated relief and slope maps helped in understanding the topographic influences on erosion processes.

### 2.5. Buffering and Overlay Analysis

A buffering technique was applied to erosion sites to assess the extent of erosion impact. Buffer zones were created at uniform distances around the affected areas, enabling the identification of high-risk zones. Multiple buffer rings were used to analyze the progression of erosion over time. Overlay analysis was then performed to examine the spatial relationship between erosion sites and various land use patterns, such as agricultural fields, roads, and settlements. This helped in determining the area's most susceptible to further degradation.

### 2.6. Statistical and Regression Analysis

The study employed statistical techniques, including Analysis of Variance (ANOVA), to compare erosion severity across different locations. Simple regression analysis was used to predict erosion rates based on independent variables such as soil texture, rainfall, slope gradient, and organic matter content. The regression equation used in this study is represented as:

$$Y=B0+B1X+\varepsilon Y = B\_0 + B\_1X + \backslash varepsilon$$

**Y** represents the erosion rate, **X** represents the independent variables, **B_0** and **B_1** are regression coefficients, and **ε** denotes the error term (Tekwa et al., 2013). The coefficient of determination ($R^2$) was used to evaluate the explanatory power of the regression model.

### 2.7. Soil Sampling and Laboratory Analysis

Soil samples were collected from multiple erosion sites at a depth of 0-15 cm using a bucket auger. The collected samples were air-dried, crushed, and sieved for laboratory analysis to determine their physical and chemical properties. The particle size distribution was analyzed using the Bouyoucous hydrometer method (Trout et al., 1987), while bulk density was measured using the clod method (Wolf, 2003). The water-holding capacity of the soil was assessed by determining its gravimetric moisture content.

For chemical analysis, the organic carbon content was measured using the potassium dichromate oxidation method (Walkley & Black, 1934), and the total exchangeable bases (TEB) were calculated by summing the exchangeable calcium, magnesium, potassium, and sodium ions (Jackson, 1965). The results were used to determine the soil's susceptibility to erosion based on its composition and structure.

### 2.8. Soil Sampling and Analysis

Several composite soil samples will be collected for the two growing seasons. A soil sample for each of the gully features was selected at each of the study sites. Soil samples are intended to be collected using a bucket soil auger at 0 -15 cm depths in a transverse direction when the soil is relatively moist and bulked. Each composite soil sample will be stored in a well-labeled polythene bag. The samples will be air-dried, crushed, and sieved through a 2 mm sieve, then prepared and analyzed

## 3. Results and discussion

### 3.1. Physical Properties of the Soils of the Study Sites

The analysis of the physical properties of the soil across the study sites reveals notable differences between eroded and non-eroded areas. The results indicate that the sand content is significantly higher in eroded sites, with values ranging from 83.7% to 89%, whereas Site E (Amuta) and the control (non-eroded) site recorded the lowest sand content at 76.3% and 76.9%, respectively. Conversely, silt content followed an opposite trend, with the control site having the highest silt percentage (4.8%), followed by Site B (Mgbelu) and Site E (Amuta) at 3.93%. Similarly, clay content was highest in Site E (Amuta) (19.7%) and the control site (18.3%). However, the differences in particle size distribution between eroded and non-eroded sites were not statistically significant ($p>0.05$). Bulk density (BD) exhibited an increasing trend in the eroded sites, indicating compaction of the soil due to erosion. The highest BD value was recorded at Site D (Ogboro) (2.19 g/cm$^3$), while the control site had the lowest BD at 1.52 g/cm$^3$. Significant reductions ($p<0.05$) were observed in moisture content (MC), total porosity (TP), and water holding capacity (WHC) in eroded areas. The control site recorded the highest values for MC (32.22%), TP (43.8%), and WHC (28.77%), while the lowest values were observed at Site D (Ogboro) and Site B (Mgbelu), where MC was 16.12% and 10.57%, respectively, TP was 17.5%, and WHC was also lowest at 10.57% in Site B (Mgbelu). The observed decrease in moisture content, water holding capacity, and total porosity, coupled with an increase in bulk density, suggests that erosion results in the loss of finer soil particles, such as clay and organic matter, which serve as binding agents that enhance soil structure and water retention. The findings align with previous studies by Brady and Weil (2008) and Igwe and Ejiofor (2005), which also reported similar impacts of erosion on soil physical properties.

**Table 2** Mean Physical Properties of Soils of the Study Area

| Study Sites | Sand (%) | Silt (%) | Clay (%) | Texture | MC (%) | BD (g/cm$^3$) | TP (%) | WHC (%) | SS (%) | EG Shape | DA (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Absu | 83.70 | 2.60 | 13.70 | LS | 21.60 | 1.86 | 29.70 | 12.88 | 7 | V | 1.23 |
| Mgbelu | 86.30 | 3.93 | 9.70 | S | 21.28 | 1.92 | 27.40 | 10.57 | 5 | U | 0.77 |
| Nkwota | 89.00 | 2.60 | 8.40 | S | 20.88 | 1.98 | 25.30 | 10.85 | 3 | U | 0.64 |
| Ogboro | 84.30 | 0.93 | 14.70 | LS | 16.12 | 2.19 | 17.50 | 14.53 | 11 | U | 2.35 |
| Amuta | 76.30 | 3.93 | 19.70 | SL | 18.04 | 2.12 | 19.90 | 14.64 | 3 | V | 0.35 |
| Control | 76.90 | 4.80 | 18.30 | SL | 32.22 | 1.52 | 43.80 | 28.77 | - | - | - |
| LSD (0.05) | NS | NS | NS | - | 6.51 | 0.22 | 8.15 | 7.46 | - | - | - |

MC = Moisture Content, BD = Bulk Density, TP = Total Porosity, WHC = Water Holding Capacity, LS = Loamy Sand, S = Sand, SL = Sandy Loam, LSD = Least Significant Difference, Control = Non-Eroded, SS = Site Slope.

### 3.2. Chemical Properties of the Soils of the Study Sites

Table 3 also shows the mean effect of erosion on chemical properties of the soil. The result here expresses the range from 5.6 – 4.4 which indicates that the soils are generally acidic. The lowest PH values were obtained on the samples from eroded sites (E (Amuta), D (Ogboro), B (Mgbelu), C (Nkwota) & A (Absu); 4.4, 4.6, 4.7, 4.8, & 5.2). The control site (Noon-eroded) had the highest value of PH with 5.6 though the PH result does not show any significant ($p<0.05$) difference from the control site. Soil PH determines the availability of plant nutrients, the uptake and the potency of toxic substances as well as the physical properties of the soil. Available Phosphorous (AV.P) were low on the eroded sites, the lowest value was recorded on the sample from site A (Absu) (12.7mg/kg) while the highest value was obtained from control (non-eroded) with (31mg/kg).

Nitrogen (N) and Organic matter (OM) were generally low in the study sites but they were significantly ($p<0.05$) lower in the eroded soil. Sites A – E has N (0.030 – 0.020%), OM (0.60 – 0.4%), Calcium (Ca) and Magnesium (Mg) were low also in the eroded land. The lowest valves are of site C with (Ca) 2.13cmol/kg, (Mg) 1.20cmol/kg, while control has the highest value of Ca and Mg (96.73 and 2.47cmol/kg). Potassium (K) and Sodium (Na) are low in the soil at the study area, but significantly ($p<0.05$) lower in the eroded soil. The result showed that exchangeable acidity (EA) increased on the eroded site. The highest value on EA is recorded on site B (Mgbelu) with 1.59cmol/kg while the lowest is recorded on the control (non-eroded) soil with 0.08cmol/kg.

Aluminum (Al) also increased across all eroded site, Effective Cation Exchange Capacity (ECEC) and Base Saturation (BS) decreased because of erosion lowest value on ECEC was recorded site A (Absu) with 5.05cmol/kg while control (non-eroded) gave the highest value of 10.45cmol/kg. BS has the lowest value of 72.16% and highest value of 92.34% from control except for potassium EA value of chemical parameters were significantly decreased ($p<0.05$) in the eroded land. The decrease in Ca, Mg, N, P, K and increase in EA suggest unfavorable chemical changes which impair the overall fertility status of the land (soil). Also, the lower chemical properties observed in the eroded soil maybe as a result of surface runoff erosion of sediments, leaching and plant uptake which will in turn cause unavailability of plant essential nutrients. This result is in accordance with findings of Mbagwu (1988), Igwe and Ejiofor (2005) and Cerda (2002).

**Table 3** Mean effect of Erosion on the Chemical Properties of the Study areas

| Study Sites | Absu | Mgbelu | Nkwota | Ogboro | Amuta | Control | LSD (0.05) |
|---|---|---|---|---|---|---|---|
| PH | 5.2 | 4.8 | 4.9 | 4.7 | 4.4 | 5.6 | 0.65 |
| AV.P (mg/kg) | 12.7 | 25.5 | 16.3 | 19.1 | 19.6 | 31.0 | 9.03 |
| N (%) | 0.030 | 0.056 | 0.041 | 0.020 | 0.020 | 0.159 | 0.026 |
| OC (%) | 0.35 | 0.63 | 0.47 | 0.26 | 0.23 | 1.60 | 0.33 |
| OM (%) | 0.60 | 1.09 | 0.82 | 0.44 | 0.40 | 2.76 | 0.58 |
| Ca (Cmol(+)/kg) | 2.20 | 2.60 | 2.13 | 2.17 | 2.20 | 6.73 | 1.13 |
| Mg (Cmol(+)/kg) | 1.20 | 1.20 | 1.40 | 1.20 | 1.33 | 2.47 | 0.56 |
| K (Cmol(+)/kg) | 0.134 | 0.153 | 0.130 | 0.168 | 0.058 | 0.275 | NS |
| Na (Cmol(+)/kg) | 0.129 | 0.136 | 0.158 | 0.102 | 0.161 | 0.176 | 0.044 |
| EA (Cmol(+)/kg) | 1.39 | 1.55 | 1.36 | 1.49 | 1.45 | 0.80 | 0.34 |
| ECEC (Cmol(+)/kg) | 5.05 | 5.63 | 5.18 | 5.13 | 5.20 | 10.45 | 1.38 |
| BS (%) | 72.22 | 72.37 | 73.82 | 70.77 | 72.16 | 92.34 | 4.62 |
| $AL^{3+}$ | 0.27 | 0.41 | 0.27 | 0.31 | 0.21 | - | - |

AV.P = Available Phosphorus, N = Nitrogen, OC = Organic Carbon, OM = Organic Matter, Ca = Calcium, Mg = Magnesium, K = Potassium, Na = Sodium, EA = Exchangeable Acidity, ECEC = Effective Cation Exchange Capacity, BS = Base Saturation, LSD = Least Significant Difference, NS = Not Significant, Control = Non-Eroded, $Al^{3+}$ = Aluminum.

### 3.3. Percentage index of the physiochemical Properties

The analysis of soil physicochemical properties across different sites revealed significant differences between eroded and non-eroded (control) sites. The control site exhibited higher soil quality, with greater moisture content, total porosity, and nutrient availability, while eroded sites had higher sand content, lower organic matter, and increased bulk density, indicating soil compaction due to erosion. The chemical analysis showed that pH levels, available phosphorus, organic carbon, and essential nutrients such as calcium, magnesium, and potassium were notably higher in the control site, reinforcing the detrimental impact of erosion on soil fertility. Statistical analysis using ANOVA confirmed that while there were no significant differences among the eroded sites, there were substantial differences when comparing eroded sites to the control site. The control site consistently displayed higher values in key fertility indicators such as cation exchange capacity and base saturation. However, the analysis of chemical properties showed no statistically significant differences between the sites, suggesting that while erosion influences physical soil properties, chemical composition remains relatively stable across locations. The findings emphasize the critical role of soil conservation in maintaining soil fertility, as erosion significantly depletes soil nutrients and alters its structure. The uniformity in chemical properties across the study area suggests that additional factors, such as land use, climate, and microbial activity, may influence soil chemistry. Further research is necessary to explore these factors and develop targeted soil management strategies to mitigate the effects of erosion.

The results of the study indicate significant differences in soil properties between eroded and non-eroded areas. In terms of soil consistency, the liquid limit (LL) was consistently higher in non-eroded soils compared to eroded soils across all sampling points, with differences ranging from approximately 4.5% to 16.5%. A similar trend was observed in the plastic limit (PL), where non-eroded soils exhibited higher values. The plasticity index (PI), calculated as the difference between LL and PL, was negative for both soil types, which is unusual and suggests possible measurement inconsistencies or unique soil behavior that requires further investigation. Bulk density measurements revealed a substantial difference between eroded and non-eroded soils. The mean bulk density in eroded areas was 2.014 g/cm$^3$, significantly higher than the 1.52 g/cm$^3$ recorded in non-eroded areas. The calculated t-ratio of 5.37 was statistically significant at $p < 0.05$, leading to the rejection of the null hypothesis and confirming a significant difference in soil compaction between the two areas. This finding suggests that soil erosion contributes to increased compaction, which could negatively impact root penetration and water infiltration.

The study also assessed soil texture components, including sand, clay, and silt content. Eroded soils contained a slightly higher percentage of sand (83.92%) compared to non-eroded soils (76.93%). The t-test result of 2.45 suggests a moderate statistical difference in sand content between the two soil types. Conversely, clay content was higher in non-eroded soils (18.3%) than in eroded soils (13.24%), though the t-test result (-1.73) was not statistically significant. The silt content was relatively low in both soil types, with non-eroded soils having a slightly higher percentage (4.8%) than eroded soils (2.8%). However, this difference was not statistically significant, as indicated by the t-ratio of -0.40.

A major finding of the study was the significant difference in organic matter content between eroded and non-eroded soils. The mean organic matter content in non-eroded areas was 2.76%, compared to just 0.67% in eroded areas. The t-ratio of 17.5 was highly significant, confirming that soil erosion leads to the depletion of organic matter, which is critical for soil fertility, water retention, and microbial activity. Similarly, porosity was significantly higher in non-eroded soils (43.77%) compared to eroded soils (23.95%), with a statistically significant t-ratio of -6.20. This suggests that non-eroded soils retain better structure and water infiltration capacity, whereas erosion results in compaction and reduced aeration. The analysis of soil plasticity further supported these findings. Non-eroded soils had higher plastic limits (mean: 31.97%) compared to eroded soils (19.53%). The liquid limit followed a similar trend, with non-eroded soils exhibiting higher values (31.47%) than eroded soils (19.03%). The plasticity index, which measures the range of moisture content over which the soil remains plastic, also showed a significant difference, with a t-ratio of 6.28. This confirms that non-eroded soils have a higher capacity to retain water and remain pliable, whereas eroded soils lose this characteristic, making them more susceptible to further degradation. The study highlights the detrimental impact of soil erosion on various soil properties. Erosion reduces organic matter content, porosity, and plasticity, making the soil more compact and less fertile. Eroded soils also contain more sand and have higher bulk density, while non-eroded soils retain more clay, organic matter, and moisture, contributing to better soil health. The statistical tests confirm that bulk density, organic matter, porosity, and plasticity show significant differences between eroded and non-eroded soils. These findings emphasize the importance of soil conservation strategies to prevent degradation, maintain fertility, and promote sustainable land use.

**Table 4** Shows the result of the Significant difference of parameterized erodibility factor properties for eroded and non-eroded areas as P>0.05

| **Parameters** | **Eroded (x) (n=5)** | **Variance $3_1^2$** | **Non-eroded (x) (n-3)** | **Variance $3^2_2$** | **Computed t-value** | **Significant difference (t-test)** |
|---|---|---|---|---|---|---|
| Bulk density | 2.014 | 0.02 | 1.52 | 0.007 | 5.37 | Not significant |
| Porosity | 23.95 | 21.03 | 43.77 | 3.57 | -6.20 | Significant |
| Plastic limit | 19.53 | 4.40 | 31.97 | 23.10 | -1.79 | “ |
| Liquid limit | 19.034 | 4.21 | 31.47 | 22.28 | -15.27 | “ |
| Plastic index | - 0.508 | 0.003 | - 0.61 | 0.12 | 6.28 | Not significant |
| % Organic Matter | 0.67 | 0.07 | 2.76 | 0.19 | 17.5 | “ |
| % Sand | 83.92 | 17.95 | 76.93 | 0.89 | 2.45 | “ |
| % Clay | 13.24 | 16.00 | 18.3 | 5.56 | -1.73 | Significant |
| % Silt | 2.80 | 1.23 | 4.8 | 2 | -0.40 | “ |

Source: Field Work 2017

The Universal Soil Loss Equation (USLE) was used to estimate soil erosion across the study sites by incorporating key variables such as rainfall erosivity, soil erodibility, slope length, slope steepness, biological control, engineering control, and tillage practice. These factors were considered to determine the extent of soil loss and assess the erosion potential in the area. Rainfall erosivity, which reflects the potential impact of raindrop energy on soil detachment, was calculated using kinetic energy formulas. The estimated R-value for the study site was 60.33, indicating a moderate impact of rainfall on soil erosion. This suggests that rainfall intensity in the area is capable of contributing to erosion but does not pose an extreme risk. The soil erodibility factor (K), which measures the soil's susceptibility to erosion, was determined using the USLE nomograph developed by Wischmeier et al. (1971). The results classified the soil erodibility in the study sites as low, with values ranging between 0.160 and 0.188. This classification suggests that the soils in the area exhibit relative resistance to erosion, likely due to their composition, which includes clay and coarse-textured particles. Soils high in clay tend to resist detachment, while those with a coarser texture generally allow better infiltration, reducing runoff.

The predicted soil loss across the study sites varied, with values ranging between 0.17 and 0.60 tonnes per hectare per year. Among the sites, the highest predicted soil loss was recorded at site C (0.60 tonnes/ha/year), while the lowest was observed at site E (0.17 tonnes/ha/year). However, all values remained below the tolerable soil loss threshold of 6.7 tonnes per hectare per year (equivalent to 3 tonnes per acre per year). This suggests that while erosion is occurring, it is not at a level that would cause immediate concern for land degradation. Overall, the findings indicate that soil erosion is present in the study area, but the predicted soil loss remains within acceptable limits. This implies that although the study sites are exposed to erosion risks, they are not experiencing severe degradation. Nevertheless, to prevent worsening conditions, conservation efforts should focus on maintaining soil structure and minimizing factors that contribute to erosion, such as increased slope steepness and reduced vegetation cover. Proper land management strategies, including vegetation restoration, erosion control structures, and appropriate tillage practices, could further mitigate soil loss and enhance soil stability in the area.

**Table 5** Results of Analysis showing correlation of soil physical properties and erodibility

| **Location** | **Clay (%)** | **Silt (%)** | **Sand (%)** | **Organic matter (%)** | **Moisture content (%)** | **Texture class** | **Permeability TP (%)** | **Erodibility** |
|---|---|---|---|---|---|---|---|---|
| Absu | 13.70 | 2.60 | 83.70 | 0.60 | 21.60 | LS | 29.70 | 0.176 |
| Mgbelu | 9.70 | 3.93 | 86.30 | 1.09 | 21.25 | S | 27.40 | 0.183 |
| Nkwota | 8.40 | 2.60 | 89.00 | 0.82 | 20.88 | S | 25.30 | 0.188 |
| Ogboro | 14.70 | 0.93 | 84.30 | 0.44 | 16.12 | LS | 17.50 | 0.175 |
| Amuta | 19.70 | 3.93 | 76.30 | 0.40 | 18.04 | SL | 19.90 | 0.160 |
| Control | 18.30 | 4.30 | 76.90 | 2.76 | 32.22 | SL | 43.80 | 0.162 |

### 3.4. Understanding of EGEM Using Relevant Erosion Variables in the Various Sites

The results of EGEM prediction as influenced by adapted data input variables such as rainfall amount (runoff), EG length, EG depth, soil bulk density, and erodibility indices are presented in Table 6 (a-c). The results in Table 6(a) revealed that the effect of these variables expressed both negative and positive correlations with EGEM estimates of volume soil loss (VSL) in the various sites. It was observed that both soil bulk density and shear strength were negatively correlated with EGEM predicted erosion (Area Soil Loss (ASL), Volume Soil Loss (VSL), and Msaa Soil Loss (MSL)) on the aggregate, while soil erodibility indices, EG lengths, and depths were positively correlated with these soil loss categories. The soil shear strength was the major factor limiting excess erosion compared to soil bulk density, depicting reduction in EGEM predicted erosion as their value increased. On the other hand, soil erodibility, EG depth and length were positively associated with predicted erosion. Soil erodibility exerted larger impact on erosion increase compared to both length and depth of the concentrated flow channels. This result implies that EGEM predicted estimates reduced as these variables increased, while the other variables increased erosion in the study area. The observed high relationship between shear strength and EGEM predicted erosion was perhaps due to the relative concentration of exchangeable bases on one site, compared to other sites. Nachtergaele *et al.* (2001a) and Capra *et al.* (2004) also reported the impact of soil shear strength and bulk density as binding agents that resist erosion forces in soils. In addition, the influence of EG length was strongly associated with EGEM predicted estimates, compared to EG depths. Similar relationship was observed previously with EGEM applications in the Mediterranean areas (Nachtergaele *et al.*, 2001a, b; Capra *et al.*, 2004; Nasri *et al.*, 2008) and in other parts of the World (Zhang *et al.*, 1998).

Results in Table 6(b) showed that there were relationships between the erosion variables and EGEM estimates of VSL in the various sites studied. Results indicated that soil bulk density strongly correlated with the predicted erosion (ASL and VSL) at all sites, except at Ogboro. The strength of their association ranged within an r2-value of 0.05 - 0.99, and it was followed in the order: Control (0.99) ≥ Mgbelu (0.98) ≥ Absu (0.89) ≥ Nkwota (0.81) ≥ Amuta(0.79) > Ogboro (0.05). The effect of the adapted erosivity limit (>20 mm) expressed a weak correlation with VSL in the sites, except at Amuta and Control, with higher r2-values of 0.71 and 0.91, respectively.

**Table 6** (a – c) Understanding between the EGEM prediction and erosion predictor variables Relationship (linear regression) between some erosion predictors and EGEM estimates of ASL, VSL, and MSL across the study area

| Predictor Variable | Coefficient of determination $R^2$-Value | | |
|---|---|---|---|
| | ASL | VSL | MSL |
| Bulk density (Mg/m-3) | -366.35 | -1080.25 | -1254.68 |
| Soil erodibility index | 121.38 | 179.55 | 216.47 |
| Soil shear strength (Nm-2) | -778.65 | -2725.45 | -3310.08 |
| EG length (m) | 0.500 | 0.29 | 0.39 |
| EG depth (cm) | 8.57 | 8.30 | 10.70 |

Association between some erosion predictors and EGEM estimates of VSL in the various sites

| Study Area | Bulk density | Runoff volume | EG length | EG depth |
|---|---|---|---|---|
| | Coefficient of determination $R^2$-Value | | | |
| Absu | 0.89 | 0.16 | 0.38 | 0.13 |
| Mgbelu | 0.98 | 0.41 | 0.66 | 0.07 |
| Nkwota | 0.81 | 0.52 | 0.89 | 0.99 |
| Ogboro | 0.05 | 0.05 | 0.73 | 0.45 |
| Amuta | 0.79 | 0.71 | 0.64 | 0.04 |
| Control | 0.99 | 0.91 | 0.95 | 0.13 |

Association between EG length and estimates of EGEM and measured erosion (ASL) in the various sites

| ASL ($m^2$) | Absu | Mgbelu | Nkwota | Ogboro | Amuta | Control |
|---|---|---|---|---|---|---|
| Measured | 0.11 | 0.20 | 0.96 | 0.76 | 0.00 | 0.95 |
| EGEM | 0.98 | 0.46 | 0.98 | 0.81 | 0.92 | 1.00 |

On the other hand, adapted EG length expressed a generally high correlation with the EGEM predicted VSL estimates in the sites, except at Absu with the least r2-value of 0.38. The influence of EG depth on EGEM adaptation was generally poor, except at Nwota with a high r2-value of 0.99. It was observed that EG length was the major determinant of erosion (VSL), followed by soil bulk density, as was similarly reported by Nachtergaele *et al.* (2001a,b).

The results in Table 6(c) further presented the relationships between ASL values and EG length sensitivity tests, which portrayed a poor correlation between the actual erosion and EG length at Amuta (r2 = 0.00), Absu (r2 = 0.11), and Mgbelu (r2 = 0.20), while it strongly correlated with length at Nkwota (r2 = 0.96), Control (r2 = 0.95), and Ogboro (r2 = 0.76). On the other hand, the EGEM predicted ASL were positively correlated with length at all sites, except Mgbelu that had weaker correlation (r2 = 0.46) with the EG lengths.

### 3.5. Estimates of EGEM Predicted Soil Loss Using Initial Input Variables

The results of standard EGEM using initial values of relevant input variables are presented in Table 7.

**Table 7** Estimates of measured and initial EGEM predicted area of soil loss (ASL), volume of soil loss (VSL), and mass of soil loss (MSL) in the study area

| Study Sites | Area of Soil Loss ($m^2$) | | Volume of Soil Loss ($m^3$) | | Mass of Soil Loss (kg/ha) | |
|---|---|---|---|---|---|---|
| | Measured | EGEM | Measured | EGEM | Measured | EGEM |
| Absu | 98.38 | 103.12 | 48.35 | 194.18 | 77.13 | 190.34 |
| Mgbelu | 109.60 | 183.12 | 201.01 | 116.08 | 139.42 | 212.16 |
| Nkwota | 276.05 | 215.78 | 172.13 | 92.10 | 110.52 | 134.96 |
| Ogboro | 116.95 | 91.60 | 121.25 | 107.14 | 217.13 | 198.34 |
| Amuta | 110.20 | 123.06 | 99.01 | 191.13 | 119.06 | 200.19 |

From Table 7, the measured erosion ranged from 98.38 – 276.05 $m^2$, 48.35 – 201.01$m^3$ and 77.13 – 217.33 kg/ha in respect of ASL, VSL and MSL while EGEM soil loss ranges from 91.60 – 215.78m2, 92.10 – 194.13m3, 134.96 – 212.16kg/ha respectively.

Also, from Table 7, it is noticed that the measured and the EGEM soil loss varied among sites with the highest in term of measured soil loss at Nkwota under the area of soil loss, Mgbelu in Volume soil loss and Ogboro in mass of soil loss while the lowest at Absu in term os ASL, VSL, MSL etc but for EGEM predicted area of soil loss was higher at nkwota follow by Absu in volume of soil loss and Mgbelu in Mass of soil loss, and lower at in both years. However, both EGEM and measured erosion exhibited repeated patterns, especially in volume and mass of soil loss across sites.

#### *3.5.1. Justification of Active Soil Erosion at the Study Area*

To substantiate on the reality of soil erosion and its alarming impact in the study area, Physio-Chemical properties were determined. Communicative map of the study area was developed. However, with consideration to the growing global climatic change, with its associated shifts in paradigm, triggered by population growth, poverty and poor land management procedures; has triggered the alarming rate of soil erosion in the southeastern part of Nigeria (Ogbonna 1997).

#### *3.5.2. Erosional Impact on Roads within the Study Area*

Roads among other things in the study areas are affected by gully erosion. However, to determine the extent of the impact, we examined the road network within the study area by using Geographic Information System application to perform an overlaying operation between the road layers and erosion layer.

#### *3.5.3. Erosional Impact of the Infrastructure in the Study Area*

In most of the areas ravaged by erosion, the level of impact on infrastructures has been enormous. Houses are washed into the gullies, sometimes with their inhabitants.

Well design drainage channels and properly terminated are also destroyed. This shows the impact of soil erosion at terminated end of the drainage channel of the main entrance of Abia State University. Investments are abandoned due to erosion. This shows an abandoned Commercial Secondary School and an attached PellyPetrol station at Mgbelu Umunnekwu. This type of devastation abounds in the study area. In some cases, social infrastructures are damaged.

#### *3.5.4. Erosional Impact of the Economic in the Study Area*

The description of the world as a complicated place (Proops, 1989) highlights the problem of quantifying the economic impacts of soil erosion. Most economists such as Barbier (1987; p.104) recognize that "given that many of the qualitative dimensions of erosion, its various trade-offs cannot be quantitatively measured, and precise analysis of all benefits and costs cannot be assured". Though the "effects" of land degradation are often difficult to trace (Upstill and Yapp, 1987), only little attention is being paid to monitoring and measuring accurately the impacts of erosion. Despite some advances that have been made in understanding the impacts of human activities, many attempts to apply cost-benefit analysis to problems of erosion and soil conservation are not very convincing (Lockeretz, 1989) and are often frustrated by imperfect information(Chisholm, 1987).

In developing countries, the estimation of the economic impact of soil erosion has been described as a daunting subject to pursue (Pearce et al., 1990 p.11) due to the general fuzzy nature of the subject. This is because of the inability to identify and measure the environmental impacts, and then, translate them into monetary terms in the formal analysis. The application of overlay, split and buffering operations of GIS as shown has been able to quantitatively estimate the extent of erosion over time as basic for the valuation procedures and other financial estimates for erosion control.

### 3.6. Mining and excavation

The area of study is richly endowed with lateritic soils which are of immense benefit to civil engineering works. Mining of these soils for construction purposes has led to exploiting the resources in an uncontrolled and reckless manner to the detriment of the environment. This uncontrolled mining has led to vast degradation and is continuing. Despite the existing regulations by Government on mining, there are no strict interventions by either the Local Government, or State Government to enforce these regulations. Rather, everyone is interested in the financial resources [tax or royalties] therefrom and not on the negative environmental impact. This mining and excavation have left most parts of Uturu, Okigwe, Ishiagu, Lokpa-Nta and Lokpa-Uturu as areas of badland topography.

### 3.7. Agriculture

Because of population pressure there is continuous cropping, and the technique commonly adopted is the slash-and-burn. No matter the effort of Government, this approach exposes the topsoil to the vagaries of weather which reduces its quality through loss of the nutrient-rich upper layers, and the reduction in water holding capacity of the soil. In this sense, 'the cream of the soil' is removed. More so tillage in the study area which involves the use of the traditional hoe redistributes soil, resulting in thinner soils on topographically convex areas of the plot causing displacement of soil nutrients during the heavy rains associated with the area, thereby decreases agricultural yields.

However, to enhance yield and ameliorate the impacts of erosion, there is an extensive use of fertilizer by these rural farmers which are provided by State and Local Government at subsidized rates, and ridges made across the slope to act as breaks for the overland flow. Farmers, who cannot afford the price of fertilizers, spread animal dung on their farms.

### 3.8. Civil engineering works

Roads, buildings, bridges, culvert construction, urbanization, and industrialization activities are associated with the complete removal of vegetation, which leaves bare surfaces for the initiation of soil erosion. In most parts of the study area, these activities are carried out without recourse to regulations and standards despite the devastating results on the environment. Sub-standard materials are used during construction, which presents a short-term solution. Structural failures on drainage sidewalls, tarred roads, and river embankments abound, which are fallouts of the business-as-usual syndrome of the Nigerian Nation.

### 3.9. Summary

EGEM estimates of VSL and MSL were significantly (*P*<0.05) higher at Nkwota and respectively lower at Control (non-eroded) and Ogboro in both years. Hence, the measured estimates were consistently higher at Mgbelu and lower at Control conserved with vegetative barriers. In addition, the $EGEM_{std}$ model efficiency in predicting erosion was reliable at most of the study sites in terms of annual VSL and MSL but was unsuited for ASL prediction. The adjusted EG length improved $EGEM_{Al}$ predictions than both adapted depth ($EGEM_{Ad}$) and standard $EGEM_{std}$ in this study.

## 4. Conclusion

The present study of soil erosion substantiates the fact that the environmental damage cause by erosion is complex, monistic and distorted. Nevertheless, it is very important to know that Soil erosion is a major problem in all the study areas and hence calls for serious and urgent attention and models that explicitly address these problems. Gully erosion is not a process limited to badlands, mountainous and hilly regions but a global and serious cause of land degradation affecting a wide variety of soils prone to crusting and/or piping. Although many strategies to prevent and combat gully erosion have proved to be effective, they are rarely adopted by farmers in the long run and at a large scale.

This research, however, adapted a model that shows the dynamics of both the soil loss and the available physio-chemical properties of the soil in the study location. However, the study avails to clinch that EGEM stayed flexible using the observed erosion variables, which exhibited both increasing (soil erodibility, EG depth, and length) and decreasing (soil shear strength and bulk density) effects on the extent of predicted soil loss by EGEM under local conditions of Isuikwuato environment. Both EG length and soil bulk density strongly influenced erosion behavior, in addition to EG depth. Soil loss magnitudes varied with EG channel sizes, and the channels voided more. Therefore, any conservation method(s) that could reduce EG depth and length advances are strongly recommended as essential EG erosion control in the study area.

## Compliance with ethical standards

*Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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