Spatial Variability of Soil Texture as a Determinant of the Erodibility Variable at Gullies in Eastern Nigeria

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Abstract: The soil texture (%sand, %silt and %clay) variable is a determinant of the erodibility variable linked to the severity of gully erosion. In Eastern Nigeria, a region in Nigeria where gully erosion predominates, the two variables have been studied in a segmented manner focusing only on localities, states and river basins, without a coverage of the area and the two concepts. Therefore, this study investigated the variability of soil texture as a determinant of the erodibility variable in Eastern Nigeria. The purposive sampling technique was used in selecting the nine most gully erosion-risk areas, one in each of the nine constituent states of the region. Then, one gully bearing the same name with the community where it is located was conveniently sampled from each of the most nine gullied areas, making a total of nine gullies. Physical observation, satellite imagery and experimental methods were used in collecting data from primary sources. A total of eighty-one (81) soil samples were collected, nine from each of the gullies at depths of 0-30cm, 30-60cm and 60-90cm for laboratory tests and analyses to determine %sand, %silt and %clay with which the erodibility variable was quantified. Results indicated that all of mean percentage sand, silt and clay as well as mean erodibility varied across the gullies. Nonetheless, %sand, %clay and erodibility varied significantly ($p = 0.00 < 0.05$) across the gullies: $R = 0.843$, $R^2 = 0.710$; $R = 844$, $R^2 = 713$; $R = 0.908$, $R^2 = 0.824$ respectively, as %silt did not. The implication is that it is the sand and clay fractions, found to be high and low respectively that really and significantly determined the degree of the erodibility variable, gully erosion intensities plus problems. The study recommended avoidance of tillage during the rains, use of mulching and compost manure, use of plant charcoal, among others for improving the quality of soil texture as a panacea for lowering the erodibility variable and invariably gully erosion incidences in Eastern Nigeria.

Keywords: *Eastern Nigeria, Erodibility, Gully erosion, Soil texture, Variability*

Conflicts of interest: None
Supporting agencies: None

Received 23.12.2023; Revised 19.02.2024; Accepted 24.02.2024

Cite This Article: IGWE, P.U., AJADIKE, J.C., OGBU, S.O. (2024). Spatial Variability of Soil Texture as a Determinant of the Erodibility Variable at Gullies in Eastern Nigeria. *Journal of Sustainability and Environmental Management*, 3(1), 36-46.

1. Introduction

Gully erosion constitutes a hazard with a remarkable footprint in the soil wherever it occurs across the globe. The planet earth is increasingly becoming in trouble because of the rising incidences of gully erosion present in all continents (Igwe, Ajadike and Ogbu, 2023). Gully erosion creates a lot of adverse environmental and socio-economic impacts the world over, exemplified by huge soil loss and sedimentation of low-lands and waterbodies (Olivier, Van De Weil and Clercq, 2023), destruction of roads and properties (Oluyori and Ojo, 2021), factor of the global climate change (Tan, Leung, Li, Tsefa, Zhu and Huang, 2020) and loss of human lives (Okwu-Delunze, Iwueke and Aniagolu, 2018). The fall-out of gully erosion calls for its management. This management depends on sound understanding of the interaction of the driving force of rainfall as an agent with the opposing force of erodibility (Isikwue, Abutu and Onoja, 2012; Abubakar, Udochukwu and Enokela, 2021). Erodibility is the vulnerability of soils to erosion (Obiora-Okeke, 2019). In the view of Minnesota Pollution Control Agency (2021), erodibility describes a measure of the inherent resistance of geologic materials (soils and rocks) to erosion. In the context of this study, erodibility is the sensitivity of a soil to be detached and transported, depending on the soil type, in soil erosion processes: rainsplash, sheet, rill and gully erosion. Erodibility has been linked to the severity of gully erosion the world over by some researchers (e.g.

Bryan, 2000; Ibeje, 2016; Song, Liu and Cao, 2020). It is determined by a number of factors, mainly soil texture, organic matter and soil aggregate stability (Ostovari, Moosavi, Mosaffari, Proppiel, Tayebi and Damatte, 2022; Devkota, Mrabet, Moussadek and Yigezu, 2022). Soil texture refers to the relative sizes of soil particles known as textural fractions or separates, namely: sand; silt; and clay (Khudhair, 2019) and it varies spatially, determining the erodibility variable in a relationship: Clay ratio (erodibility) = $\frac{\%\text{sand}+\%\text{silt}}{\%\text{clay}}$, according to Bouyoucos (1935).

From the above regression equation, it is evident that two components (%sand and %silt) and one component (%clay) of the soil structure vary directly and indirectly respectively with erodibility. It implies that as sand and silt fractions of the soil increase, the erodibility rises which translates into more gully erosion. So soils with high values of the two are very dispersible unlike those with lower values. On the contrary, another implication is that as the clay fraction increases, the erodibility is lowered, but increases as the clay fraction decreases. So soils with high percentage of clay are less erodible than those with low clay contents which are easily eroded. No doubt, the knowledge of variability of the soil texture as a determinant of the erodibility variable is very crucial for understanding the variability and extent of gully erosion of any area like Eastern Nigeria so as to employ different and suitable approaches as remediation strategies for gullies.

Many researchers have conducted studies to indicate the variability of soil texture (percentage sand, silt and clay fractions of soils) as well as erodibility it determines across the globe. Egbuchua (2014) reported that the variant ratio tests for sand, silt and clay were 84.4%, 0.15% and 15.45% respectively in an Utisols in Tropical Region, Delta State, Nigeria. Awoonor and Dogbey (2021) observed variations in most soil attributes of sand, silt and clay as 69.50%, 21.00% and 9.50% respectively in the toposequence of the tropical moist semi-deciduous forest of Ghana. In the perspective of Lipiec and Usowrez (2017), the mean percentage of sand, silt and clay was found to have varied, ranging from 4.8-4.9%, 34.0-49.7% and 62.5-63.2% respectively in Trezbieszow region, Podlasic, Poland. Banja (2020) contended that the percentage of sand, silt and clay was 50, 33 and 17 respectively in Adami Tulu, Jido Kamboliha District, Oromiya Region, Ethiopia. The variation of mean percentage sand, silt and clay at four gullies in parts of Kaduna State, Nigeria was 53.18, 32.23 and 14.38 respectively (Oluyori and Mgbanyi, 2014).

Sand, silt and clay fractions were found to have varied in Ri-Bhoi District, India, exemplified by the variation of sand as follows: 32.17%, 18.39%, 27.37% and 37.96% in agriculture, Ihum, forest and wasteland respectively (Olaniya, Bora, Das and Chanu, 2020). Wang, Chen, Thang, Chen, Xianggian, Liu and Hu (2018) stated that the percentage variation of silt and clay particles of 150mm was greater than that of 170mm by 18.12%, however, sand fractions at 170mm was higher than those of 150mm by 19.72% in the three Gorges Reservoir, China. In the opinion of Polakowski (2021), from one out of the 30 repetitions for each soil, the variation percentage of sand, silt and clay was 89.02, 10.19 and 0.79 respectively in Poland. The variations in the range of sand, silt and clay were 54.43-41.00%, 20.70-29.7o% and 20.92-29.10% in that order in Halda River, Chaltogong, Bangladish (Sajeeb, 2021). In the view of Ogban (2021), total sand, silt and clay varied thus: 864.00gkg-1, 45.00gkg-1 and 91.00gkg-1 respectively in University of Uyo Teaching and Research Farm, Akwa Ibom State, Nigeria.

Like soil texture, erodibility determined by it also varies spatially. According to Ezeabasili, Okoro and Emengini (2014), the erodibility indices of some soils from Anambra Basin in twelve locations with severe gully erosion indicated variability ranging from 0.21-24.64. In Imo and Abia states of Nigeria, erodibility values ranged from 34 (0.34) to 72 (0.72) at Arondizuogu and Isikwuato respectively (Ibeje, 2016). Oluyori and Mgbanyi (2014) revealed mean erodibility indices in an ascending order of variability of four studied gullies as follows: Yashi (3.58); Saye (4.02); Kubani (10.89) and Guga (13.06), which are parts of Kaduna State, Nigeria. In the contention of Hanna and Macin (2021), the erodibility (K) ranged between 0.0172 and 0.0352 across soil profiles classified in four groups of varying degrees: completely eroded, strongly eroded, slightly eroded, and non-eroded forest in northern Poland. For three different land uses: forest, agricultural and residential in Keana Geologcal Sediments of parts of Nasarawa State, Nigeria, Abubakar, Udochukwu and Enokela (2021) found the variability of mean erodibility values of the soils of the three land uses as 0.0492, 0.0460 and 0.0357 respectively.

Although many small, medium and large gullies dot the geographical space of Eastern Nigeria, all previous studies known to the researchers on the variability of soil texture (e.g. Ogban, 2021) and erodiblity (e.g. Ezeabasili et al., 2014; Ibeje, 2016) in Eastern Nigeria, a region in Nigeria where gully erosion is dominant, have been conducted using a piecemeal approach in both coverage of the area and the two variables. These studies covered localities, river basins and states only. Additionally, none of them indicated the variations of %sand, %silt and %clay constituting soil texture as a determinant of erodibility in the region. Hence, this study investigated comprehensively the variability of soil texture as a determinant of the erodibility variable in the region so as to fill the gap and contribute to the body of knowledge. This research differs from previous ones in Eastern Nigeria because it addressed how the soil texture variable determined the erodibility variable in the region.

2. Materials and methods

2.1. Study area

The study was carried out in Eastern Nigeria, which is a region in Nigeria (Figure 1) where gully erosion is dominant, and its nine communities with large gullies located in Mgbarakuma, Ikot Ayan Itam, Oko, Igbogene, Ikot Nkebre, Ocha-Ekoli Edda, Abia, Ozu Urualla and Umuebulu II in Abia, Akwa Ibom, Anambra, Bayelsa, Cross River, Ebonyi, Enugu, Imo and Rivers states respectively. The communities are situated in the nine most gully erosion-risk areas with large gullies in Umuahia (Abia), Itu-Uyo (Akwa Ibom), Agulu-Nanka-Oko-Ekwulobia (Anambia), Yenagoa (Bayelsa), Calabar (Cross River), Ekoli-Nguzu Edda (Ebonyi), Udi-Nsukka (Enugu), Ideato-Orlu (Imo) and Oyigbo-Eteche (Rivers) respectively according to National Geo-Hazards Monitoring Centre, Awka (NGHMCA) (2019). The region has a total land mass of 46,977km^2. From the region's base population of 30,092,822 persons in 2006 (National Population Commission [NPC], 2010) and population growth rates for Nigeria ranging from 2.67-2.55% between 2007-2023 according to the United Nations (2023), the number of human beings in the region has been estimated to be 46, 809, 600 persons in 2023.

The region is located between latitudes 50 0′ 0″ N, 70 0′ 0″ N of the equator and longitudes 60 0′0″E, 90 0′ 0″E. It consists of the contiguous states of Abia, Akwa Ibom, Anambra, Bayelsa, Cross River, Ebonyi, Enugu, Imo and Rivers. It is bounded on the east by the Cameroon Highlands, west by the River Niger, north by Kogi and Benue states and the Atlantic Ocean in the south, along the Gulf of Guinea. It was formerly administered as Eastern Nigeria before the Nigerian-Biafran civil war that erupted in 1967 till 1970. From1967 to 1996, the region had metamorphosed politically, through its balkanization by various military juntas who ruled Nigeria over the years, into its present nine constituent states (Figure 2).

Geologically, it is characterized by several mega structural features, notably the Calabar Flank, the Mamfe Embaymeul, the Anamba Basin, the Afikpo Syncline, the Abakaliki Anticlinorium, the Niger Delta, the Oban Massif and the Obudu Plateau (Bassey, 2012) as indicated in Figure 3. The geology of the area influenced gully formation and expansion as well as massive landslides that happened in several communities because the Ameki Formations, Nanka Sands, Ajali Sands and Coastal Plain Sands in the area are very susceptible to the forces of denudation anywhere they were exposed as sandy outcrops (Egboka and Okoyeh, 2016). The region lies within the tropical rainforest and derived savanna belts, with abundant rainfall ranging from 4000mm on the coastal sea board to below 1700m in the Udi-Nsukka Plateau (United Nations Development Programme [UNDP], 1995), varying land forms, scarcely thick natural vegetation and many natural resources like huge crude oil/natural gas reserves, lead, limestone and gold. According to UNDP, the mean annual maximum temperature ranged between 30^0 C in Calabar and Port Harcourt to 33^0 C in Enugu whilst the mean annual minimum temperature decreased from the interior to the coast, ranging from 29^0 C to 21^0 C.

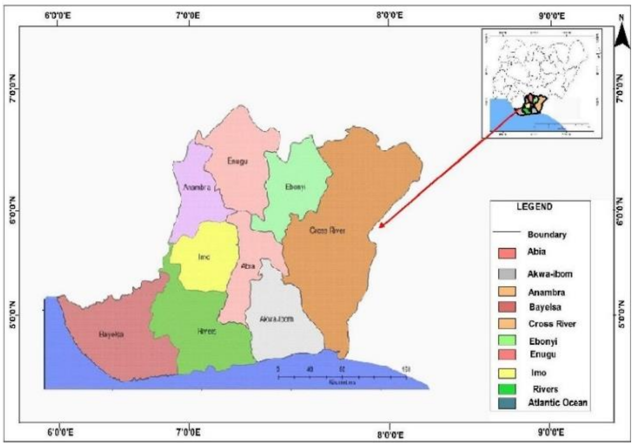

Figure 1: Map of Eastern Nigeria in the map of Nigeria Source: National Geo-Hazards Monitoring Centre, Awka (NGHMCA), 2020

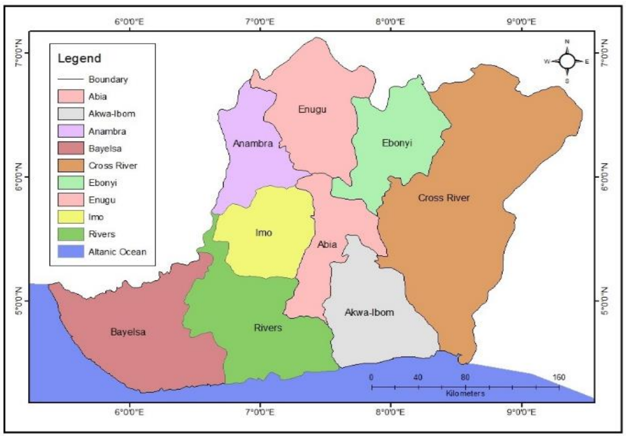

Figure 2: Map of Eastern Nigeria indicating her nine constituent states - National Geo-Hazards Monitoring Centre, Awka (NGHMCA), 2020

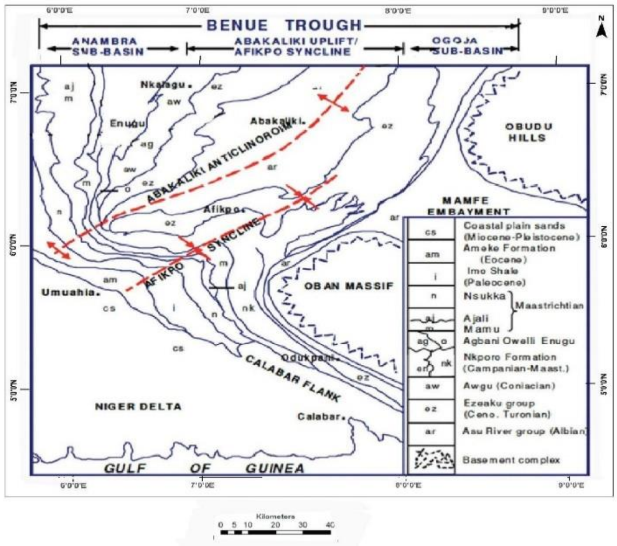

Figure 3: Geological map of Eastern Nigeria indicating the various mega structural features (Adapted from Bassey, 2012)

2.2. Sampling methods and data analysis

Two sampling technique were employed in the course of the research. Firstly, the nine most gully erosion-risk areas with large gullies were purposively sampled. The technique was chosen with a clear aim of investigating how the variabilities of soil texture determined the sensibilities of the soils to erode at only the gullies where incidences of erosion occurred highest in Eastern Nigeria. Secondly, the convenience sampling technique was used in selecting nine large and active gullies that were accessible and in close proximity to human settlements with proofs of failed remediation strategies. Each gully bears the same name with the community where it is located. The reasons for selecting the nine communities alongside its large gullies were: (i) presence of active gullies in the communities within the most gully erosion-risk areas; (ii) communities where residents live in close proximity to the gullies; and (iii) accessibility to the gullies through the chosen communities. The geographical locations of the investigated gullies were taken at points 5m (measured using a 5m long bamboo) away from the edges of the gullies at the head-scraps, using a GPS-76 Marine Investigator to show their co-ordinates whilst the elevations of the points above sea level were also taken by making use of the same instrument (Table 1). The tape was used in measuring the lengths and widths (1m each) of the soil profile pits as well as their common depth (0.9m) from which soil samples were taken at depths of 0-30cm, 30-60cm and 60-90cm, measured using the same tape. Again, the distance of 5m from the edge of each gully at its head-scrap was taken using the five-metre long bamboo instead of a tape to avoid falling inside the gullies whose haed-scraps where active gully erosion process occurs highest were the most unstable.

The experimental method was used for the generation of quantitative data from primary sources. A total of eighty-one (81) composite soil samples were collected from the nine investigated gullies. At each of the studied gullies, three soil profile pits measuring 1m x 1m x 0.9m were dug at a distance of 5m, measured using a 5-metre long bamboo, from the three edges of the gully, one at the head-scrap and one at each of the two shoulders (sidewalls), 5m away from the head-scrap. The headscraps and shoulders near to them were chosen because these are where gullying occurs highest in its upslope movement and sidewall expansion. Three soil samples were collected from each of the pits at depths of 0-30cm, 30-60cm and 60-90cm. The three layers were chosen at the top soil (0-30cm) that must be eroded before gullying starts, at the point where gully erosion begins from the sub-soil (30-60cm) and even beyond (60-90cm) as gullying continues for a proper understanding of mean soil erodibility from the top soil to two layers of the sub-soil. The collection of soil samples was conducted during the dry season between 10th-12th March, 2020 before the lockdown due to the Coronavirus disease, 2019 (COVID-19) pandemic, when the gullies' edges and their environs were considerably and seemingly stable and safe to a large extent. At each of these nine sampling locations, a digger and a shovel were used in creating the soil profile pits while a trowel was used in carefully collecting the soil samples at the various depths, starting from the last stratum (60-90cm) to avoid contamination by the upper ones (30-60cm and 0-30cm), then the second (30-60cm) so as to avoid contamination by the first (0-30cm), which would have been the case if the collection happened in a reverse order beginning from the first.

The samples were homogenized in a clear plastic plate and a composite soil sample was drawn from each. This process was repeated for all the experimental units in the laboratory. Each of the nine soil samples from Mgbarakuma (Abia); Ikot Ayan Itam (Akwa Ibom); Oko (Anambra); Igbogene (Bayelsa); Ikot Nkebre (Cross River); Ocha Ekoli-Edda (Ebonyi); Abia (Enugu); Ozu Urualla (Imo); and Umuebulu II (Rivers) were wrapped in threes according to the three layers and poured into nine separate small polythene bags labelled SSA, SSB, SSC, SSD, SSE, SSF, SSG, SSH, and SSI respectively. The nine small bags were then put into a big polythene bag. It is noteworthy that at the end of each day (10th and 11th March, 2020), the soil samples collected were preserved in the refrigerator in the hotels where the researchers lodged. Then on 12th March when the collection of the 81 soil samples was completed, they were all transported immediately to the laboratory of the Department of Soil Science and Technology, Federal University of Technology, Owerri for soil particle size distribution analysis.

The soil samples were air dried and standard laboratory methods were used in determining the soil properties following standard laboratory procedures (Gee and Or, 2002; Grossman and Reinesch, 2002). Soil particle size distribution was determined using the hydrometer method. Clay ratio indices which are the erodibilities of the soils at the gully erosion sites were computed by using figures of particle size distribution (%sand, %silt and %clay) to determine the levels of resistance of soils to gully erosion across the investigated gullies. The clay ratio (erodibility) indices were computed using the aforementioned Bouyoucos' (1935) model. Data generated on both soil texture and erodibility indicated their variabilities across the investigated gullies in the region. The Multivariate and Univariate Analysis of General Linear Model (GLM) of SPSS, Version 22. 0 were used in data analysis on the variations of soil texture (%sand, %silt and %clay) and erodibility across gullies in the region respectively. The variations were tested at $p < 0.05$.

Table 1: Locations and elevations of the investigated gullies in the nine studied communities in Eastern Nigeria

S.N.	State	Gully site	Gully location	Elevation (m)
1	Abia	Mgbarakuma	E07º 25' 17" N05º 28' 23"	144.6
2	Akwa Ibom	Ikot Ayan Itam	E07º 59' 07" N05º	37.8

			07' 17"	
3	Anambra	Oko	E07° 05' 08" N06° 02' 20"	267.6
4	Bayelsa	Igbogene	E06° 24' 10" N05° 02' 41"	10.8
5	Cross River	Ikot Nkebre	E08° 21' 30" N05° 03' 46"	64.2
6	Ebonyi	Ocha-Ekoli Edda	E07° 50' 18" N05° 44' 44"	184.1
7	Enugu	Abia	E07° 24' 53" N06° 20' 04"	428.1
8	Imo	Ozu Urualla	E07° 03' 36" N05° 51' 45"	102.9
9	Rivers	Umuebulu II	E07° 08' 35" N04° 53' 21"	15.5

Source: Researcher's Field Survey, 2019

3. Results and discussion

3.1. Variations of soil texture (%sand, %silt and %clay) and erodibility

The soils at the nine investigated larger gullies, exemplified by Oko, Ocha-Ekoli Edda and Umuebulu II gullies (Plates 1, 2 and 3 in the Appendix) in Eastern Nigeria were found to be undergoing variations in their percentage sand, silt and clay that determine the erodibility variable. The variations of the means of the soil particle size distribution (soil texture) with their textural classes and those of the calculated clay ratios (erodibility) indices are shown in Table 2 and graphically according to stratum (0-30cm, 30-60cm and 60-90cm) in Figures 4a, 4b and 4c. Furthermore, the mean variations of each of the four variables across gullies are clearly shown graphically in Figures 4d, 4e, 4f, and 4g. The research revealed that there were variations in the means of %sand, %silt and %clay at gully sites in the region which is in agreement with the perspective of Wang et al. (2018) that percentage fractions of sand, silt and clay varied in Gorges Reservoir, China and the contention of Ogban (2021) who posited that variation occurred in total sand, silt and clay in University of Uyo Teaching and Research Farm, Akwa Ibom State, Nigeria. In a similar manner, the mean values of the erodibility indices were found to have varied across the gullies in line with the assertion of Ibeje (2016) that there was variation in the erodibility indices of soils, ranging from 34 (0.34) to 72 (0.72) at Arondizuogu and Isikwuato respectively in Imo and Abia states, Nigeria in that order as well as the opinion of Hanna and Macin (2021) that erodibility varied across northern Poland, ranging between 0.0172 and 0.0352.

The study indicated that percentage sand is very high with mean values ranging from 78.08% - 96.04% across the gullies; the variation is significant across the gullies as indicated in Table 3. The high proportion of sandy soil, which is very dispersible because it is easily detached, simply implies increased erosion in the study area. This finding conforms with the opinions of some researchers such as Uboh, Akhonbare and Onweremadu (2013) who noted that the soils of Ukpo, Nnewi South Local Government Area, Anambra State were mostly loose sandy soil which were easily dispersible, leading to gully erosion and the contention of Aigbadon, Ocheli and Akudo (2021) that the coarse-grained sand with no plasticity was the soil type which influenced gully erosion in Igusa and its environs, Southern Nigeria. In a similar manner, one of the findings of the research showed that the percentage of silt contents varied across the gullies, though not significantly. The mean values of silt range from 2.43% - 10. 39%. Although Pal (2009) submitted that silt is easily erodible, its low contents in the region play insignificant role in gully erosion as its variation across gullies was found not to be significant.

The percentage clay fractions which was found in very low proportions varied with mean values ranging from 1.53% - 12.87%. The variation of clay contents was found to be significant across the gully sites (Table 4). When the percentage of clay is low, the resistance of the soils to erosion becomes very low, which implies more erosion, but when the percentage of clay is high, the soils are more resistant to erosion, implying less erosion (Bouyoucos, 1935). For soils of the study area that generally have low percentage of clay fractions, the implication is that they are less resistant to erosion. This goes to a large extent to explain why there are many older gullies and emerging new ones in the nooks and crannies in the region.

In the realm of water-induced gully erosion, erodibility as a soil property is the most critical factor that determines the susceptibility, vulnerability or sensibility of soils to detachment by raindrops and runoff. Though the variations of other soil properties addressed in this research, namely %sand, %silt and %clay are important, how erodibility varies across gully sites is most crucial in understanding the variabilities and spatial distributions of gullies in Eastern Nigeria. This underscores the reason why it is very important to understand how the soil texture determines erodibility and also how the phenomenon varies across gullies. Table 5 shows that erodibility linked to the severity of gully erosion incidences and indeed problems varied significantly across gully sites in the study area. According to Liu, Zang and Li (2020), spatial variation is a characteristic of soil and erodibility. In line with the submission, this study revealed that erodibility indices vary spatially in a decreasing order from north to south in Eastern Nigeria, with mean values ranging from 69.71- 6.70. This accounts for the reason why gully erosion incidences and total number of large gullies in Anambra, Enugu, Imo, Abia and Ebonyi, which are states in the north, are far greater than those in the coastal states of Cross River, Akwa Ibom, Rivers and Bayelsa in the south. The implication of this result is that gully erosion will continue to happen highest in the named states in the north than those in the south due to the variable soil texture determining the high and low erodibility in the two parts of the region respectively.

Table 2: Mean soil particle size distribution (%sand, %silt and %clay) and clay ratio (erodibility) indices

Gully	Stratum	%Sand	%Clay	%Silt	Textural class	Clay ratio (erodibility) indices
Mgbarakuma	0-30	84.52	7.20	8.28	LS	12.89
	30-60	83.80	14.92	1.28	LS	5.70
	60-90	81.52	13.20	5.28	LS	6.58
	Mean	83.28	11.77	4.95	LS	8.39
Ikot Ayan Itam	0-30	83.08	7.20	9.72	LS	12.89
	30-60	83.08	5.20	11.72	SL	18.23
	60-90	72.08	19.20	8.72	SL	4.21
	Mean	79.41	10.53	10.05	SL	11.78
Oko	0-30	97.52	2.20	0.28	S	44.46
	30-60	95.52	1.20	3.28	S	82.33
	60-90	95.08	1.20	3.72	S	82.33
	Mean	96.04	1.53	2.43	S	69.71
Igbogene	0-30	85.52	7.20	7.28	LS	12.89
	30-60	81.52	4.20	14.28	LS	22.81
	60-90	87.52	6.20	6.28	LS	15.13
	Mean	84.95	5.97	9.28	LS	16.94
Ikot Nkebre	0-30	79.53	13.20	7.27	SL	6.58
	30-60	82.52	13.20	4.28	SL	6.58
	60-90	84.08	12.20	3.72	LS	7.20
	Mean	82.04	12.87	5.09	SL	6.79
Ocha-Ekoli Edda	0-30	96.08	1.20	2.72	S	82.33
	30-60	95.08	3.20	1.72	S	30.25
	60-90	95.08	1.20	3.72	S	82.33
	Mean	95.41	1.87	2.72	S	64.97
Abia	0-30	94.08	3.20	2.72	S	30.25
	30-60	90.08	6.20	3.72	S	15.13
	60-90	90.08	7.20	2.72	S	12.79
	Mean	91.41	5.53	3.05	S	19.39
Ozu Urualla	0-30	86.08	5.20	8.72	LS	18.23
	30-60	84.08	6.20	9.72	LS	15.13
	60-90	85.08	8.20	6.72	LS	11.20
	Mean	85.08	6.53	8.39	LS	14.85
Umuebulu II	0-30	86.08	9.20	4.72	LS	6.89
	30-60	64.08	13.20	22.72	SL	6.58
	60-90	84.08	12.20	3.72	LS	6.65
	Mean	78.08	11.53	10.39	LS	6.70

S=sand, LS=loamy sand, SL=sandy loam
Source: Researcher’s field survey, 2020

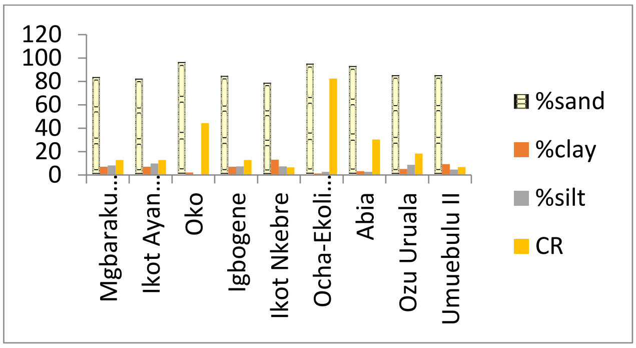

Figure 4a: Mean soil particle size distribution and clay ratio at the gullies at 0-30cm depth
Source: Researcher's field survey, 2020

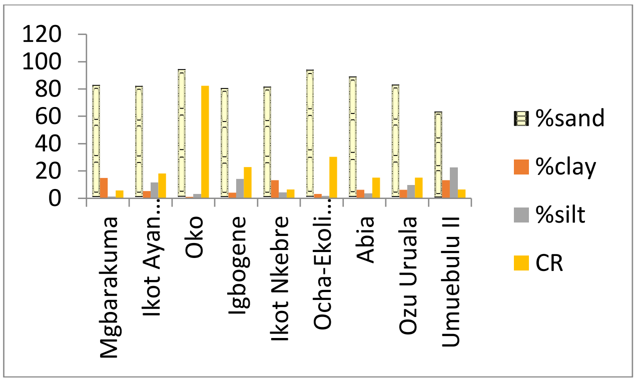

Figure 4b: Mean soil particle size distribution and clay ratio at the gullies at 30-60cm depth
Source: Researcher's field survey, 20

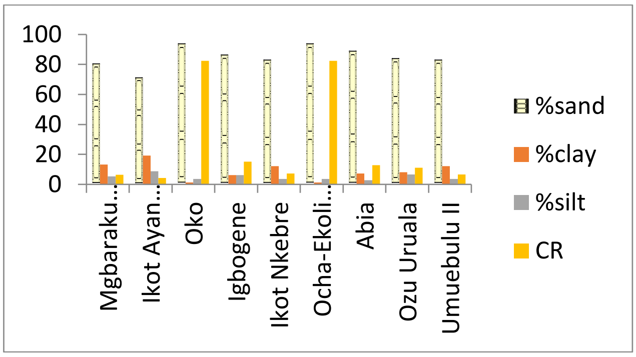

Figure 4c: Mean soil particle size distribution and clay ratio at the gullies at 60-90cm depth
Source: Researcher's field survey, 2020

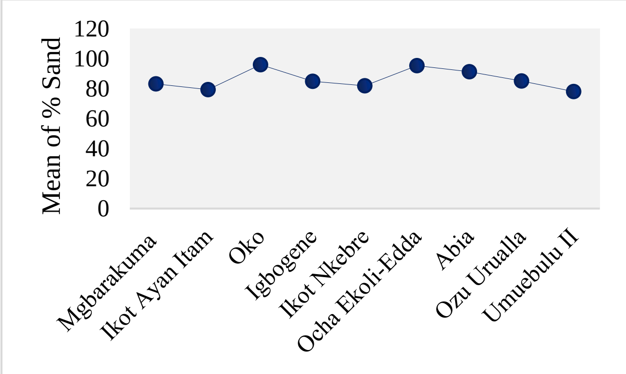

Figure 4d: Variation of % Sand across Gully Sites
Source: Researcher's field survey, 2020

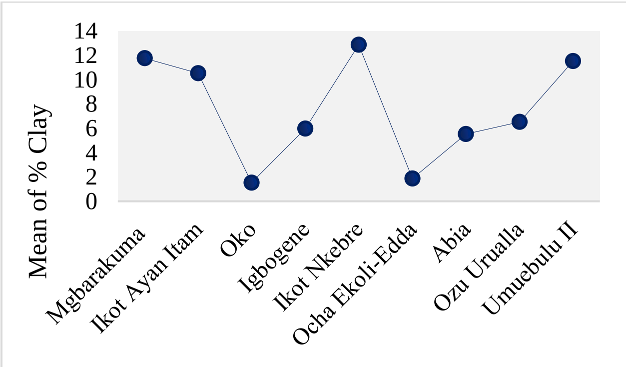

Figure 4e: Variation of % Clay across Gully Sites
Source: Researcher's field survey, 2020

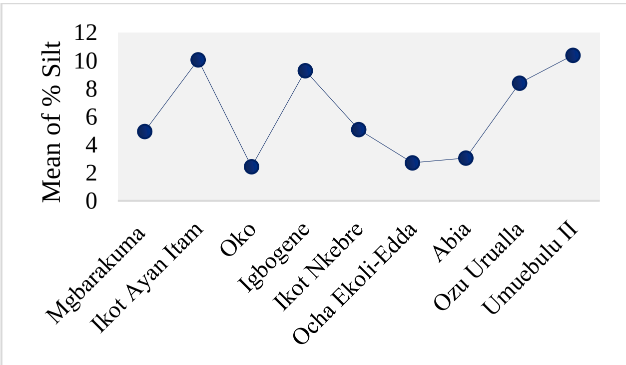

Figure 4f: Variation of % Silt with Gully Sites
Source: Researcher's field survey, 2020

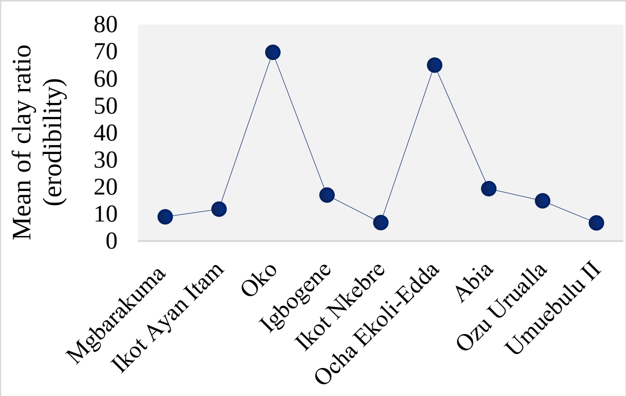

Figure 4g: Variation of Clay Ratio (Erodibility) across the Gully Sites
Source: Researcher's field survey, 2020

3.2. Statistical analysis

The Multivariate Analysis of General Linear Model (GLM), a type of Analysis of Variance (ANOVA) used to address the variations of soil texture across the gullies. The GLM was applied because it is the most appropriate statistical tool that indicates the interaction effect of independent variables on the dependent variable. In the context of this study, the soil texture constitutes the multiple variables of %sand, %silt and %clay, which underscores the reason why this type of GLM was used. The results summarized in Table 3, indicate that %sand and % clay varied significantly across the gullies (R = 843, R2 = 0.582, p =0.001 < 0.05) and (R = 0.844, R2 = 0.585, p = 0.001 < 0.05) respectively while %silt does not (R = 0.671, R2 = 0.205, p= 0.135 > 0.05). Similarly, the Univariate Analysis of GLM, which is another type of ANOVA used to address the variations of one dependent variable was applied. In this study, the dependent variable is erodibility. The results of erodibility across the gullies, summarized in Table 4, show that it varied significantly across the gullies (R = 908, R2 = 824, p = 0.000 < 0.0. The implication of the result is that it is the variables of %sand and %clay that are the significant determinants of erodibility in Eastern Nigeria. The significant variation of erodibility across Eastern Nigeria implies that the soils of the region are generally erodible, making the region prone to gullying in different degrees. This ought to be borne in mind in the establishment of large-scale development projects in the region as runoff from them can easily cause gully erosion due to the erodible soils, if not properly managed. This study has contributed to the understanding of gully erosion in Eastern Nigeria because it clearly indicated that the scientific reason why gully erosion happens more in the northern part of the region with more number of large gullies than in the southern part with lesser number of large gullies is due to the high erodibility indices of soils in the north than in the south.

Table 3: Results of Analysis of Variance (ANOVA) showing Variations of %Sand, %Clay and %Silt across Gully Sites
Test used: Multivariate Analysis of General Linear Model (GLM), SPSS Version 22.0
Tests of Between-Subjects Effects.

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	Percentage sand	1049.255[a]	8	131.157	5.520	.001
	Percentage clay	441.511[b]	8	55.189	5.590	.001
	Percentage silt	259.939[c]	8	32.492	1.839	.135
Intercept	Percentage sand	200527.071	1	200527.071	8440.348	.000
	Percentage clay	1544.660	1	1544.660	156.443	.000
	Percentage silt	1052.564	1	1052.564	59.567	.000
Gullysites	Percentage sand	1049.255	8	131.157	5.520	.001
	Percentage clay	441.511	8	55.189	5.590	.001
	Percentage silt	259.939	8	32.492	1.839	.135
Error	Percentage sand	427.647	18	23.758		
	Percentage clay	177.726	18	9.874		
	Percentage silt	318.063	18	17.670		
Total	Percentage sand	202003.973	27			
	Percentage clay	2163.896	27			
	Percentage silt	1630.566	27			
Corrected Total	Percentage sand	1476.902	26			
	Percentage clay	619.237	26			
	Percentage silt	578.002	26			

a.R=.843; R Squared = .710 (Adjusted R Squared = .582)
b.R= .844; R Squared = .713 (Adjusted R Squared = .585)
c.R= .671; R Squared = .450 (Adjusted R Squared = .205)

FTAB= 2.510
There is significant variation of sand and clay only across the gully sites.

Table 4: Results of Analysis of Variance (ANOVA) indicating Variation of Clay Ratio (Erodibility) across Gully Sites
Test used: Univariate Analysis of General Linear Model (GLM), SPSS Version 22.0
Tests of Between-Subjects Effects
Dependent Variable: Clay ratio

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	14763.740[a]	8	1845.467	10.528	.000
Intercept	16014.752	1	16014.752	91.362	.000
Gully sites	**14763.740**	**8**	**1845.467**	**10.528**	**.000**
Error	3155.208	18	175.289		
Total	33933.700	27			
Corrected Total	17918.947	26			

a. R=.908; R Squared = .824 (Adjusted R Squared = .746)

FTAB= 2.5102

There is significant variation of clay ratio (erodibility) across gully sites.

4. Conclusion

The spatial variability of soil texture (%sand, % silt and %clay) which is a determinant of the erodibility variable as a factor of gully erosion linked to its severity is of essence. This has been investigated by this study with a revelation that variations of sand and clay fractions across the studied gullies were significant whilst the variation of silt was not. The high percentage of sand contents coupled with the low percentage of clay unveiled by this study do not bind the soil particles enough as to prevent easy detachment. This makes the soils of the region to be very erodible and as such easily detachable by the forces of raindrops and runoff. By implication, it is the two variables that significantly caused the variability of erodibility, with high values in the northern part of the study area and low values in the southern part as established by this study. The study, therefore, concludes that it is the high percentage of sand and low percentage of clay fractions in the soils of Eastern Nigeria that are of significance and concern in the determination of the erodibility variable linked to the severity of gully erosion intensities in the region. Based on the results of the study indicating that the high sand and low clay fractions at the investigated gullies are of significance and concern in determining the erodibility of soils at the gullies, the following recommendation are made focused mainly on improving soil quality that would in turn reduce gully erosion incidences.

a. Avoidance of tillage during the rains: Tillage loosens soil particles and exposes them to detachment and transport by raindrops and runoff and as such should never be used as an agricultural practice around the gullies, particularly during the rainy season.

b. Use of mulching and compost manure: The use of mulching and compost manure that bind soil particles together is a good agricultural practice within the gullied areas. It is preferred to the use of chemical fertilizers that do not have any binding force on soil particles.

c. Increase in the vegetation cover at the gully erosion sites: This is achievable by planting trees whose leaves and roots provide humus and bind soil particles respectively.

d. Use of plant charcoal: This is a good soil improver. It is fairly burned organic matter like wood added to the soil for additional humus buildup.

e. Diversion of runoff from entering the gully channels: This is very crucial in reducing landslides and slumping of the easily erodible sand fractions without much clay to provide the binding force and indeed resistance to gully erosion at the gullies.

f. Environmental awareness and education programme: Community residents around the gullies should be trained to jettison all bad agricultural practices like over cultivation and cropping up to the gullies' edges which expose the erodible sand fractions that predominate at the gully sites to the forces of denudation.

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