INTERPLAY OF GEOTECHNICAL ATTRIBUTES OF SOIL IN EROSION PROCESSES OF WEAKLY CONSOLIDATED SEDIMENT FORMATION IN SOUTHEASTERN NIGERIA

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Abstract

Geotechnical attributes offer insight in the inherent properties of soil as regards its susceptibility to erosion. In this research, 28 soil samples were collected from different erosion spots and subjected to laboratory analysis at National Steel Raw Materials Exploration Agency's laboratory, Kaduna, using relevant standard and established equipment within 96 hours after collection. The laboratory data and gully slope parameters were analysed using Pearson correlation matrix to establish inter-relationships between soil parameters and gully geometry and determine the underlying factors of gully propagation. Statistical data showed that sand composition strongly related negatively (inversely) with silt/clay, which clearly indicates that both have different roles in erosion triggering and development. Sand correlated negatively with cohesion ($r = -.892$, $p<.001$), liquid limit ($r = -.932$, $p< .001$), plasticity index ($r=-.799$, $p<.001$) and bulk density ($r=-.883$, $p<.001$), which are erosion inhibiting soil properties while positively(directly) related to internal friction angle ($r=.877$, $p<.001$), gully depth ($r=.531$,$p<.001$), gully width($r=.503$, $p= .006$) and gully length($r=.685$,$p<.001$). The result implies that the higher the sand composition, the more vulnerable the soil to erosion and its propagation agents. Silt/clay are strongly related to erosion resistant soil properties such as cohesion($r=.882$, $p<.001$), liquid limit($r=.946$, $p<.001$), plasticity index($r= .808$, $p <.001$) and bulk density($r=.913$, $p< .001$), while negatively correlating with internal friction angle ($r= -.912$, $p<.001$), slope angle ($r=-.696$, $p<.001$), gully depth ($r=-.576$, $p<.001$), gully width ($r=-.525$, $p=0.01$) and gully length($r= -.713$, $p<.001$), signifying that silt/clay particles impede erosion advancement. Therefore, the amount of sand and/or clay content in a soil is an early indicator to its susceptibility to erosion.

Introduction

Soil erosion is a serious environmental problem world over with significant rise in magnitude, rate, extent and increasing dynamics (Lal, 2001; Chinemelu et al., 2013). Being a naturally occurring environmental hazard forced by man's quest for survival has increased the vulnerability of soils to erosion processes in many areas leading to hazards and irreversible soil deterioration –cum degradation (Van der Kniff et al., 1975; Bell et al., 2000).

Accordingly, various researchers (Obiadi et al., 2011; Okoroafor and Jonatthan 2017; Asuoha et al, 2019; Okenmuo et al 2021; Udoumoh et al 2021) have decried that poor land use practices including deforestation, over grazing and other associated unhealthy activities promoting soil erosion processes, (Bryan, 2000) has unravelled that the inherent properties of soil is a major determinant of its response to erosion hazards. He noted that the nature of soils correlates directly with the rate of entrainment, detachment and deposition. Egbueri and Igwe(2020) noted that soil detachment and index of liquefaction are vital in denoting the potential response of soil to forces of erosion. Egashlra et al. (1983) repeated that soil aggregate structure exerts major control on water induced erosion occurring on the earth surfaces.

In pursuance of the above, Ofomata (1985) reiterated that more efforts should be geared towards unravelling the operations of the non-anthropogenic factors of soil erosion to understand the nature of the environmental “monster” wholly. In this vein, studying the geotechnical attributes of soils in the loosely consolidated formation of south eastern Nigeria became a critical issue which shouldn’t be left to serendipity.

Appropriately, Egboka and Okpoko, (1984) explained that the intense rate of weathering occurring on the rocks supporting the terrain of the dominant section of our study area exposes it to mass wasting and other operative agents of erosion. Furthermore, it was reported that runoff facilitates bulking-off of sediment particles together with instability of slopes as occasioned by high angularities have profound effects soil erosion processes (Igwe 2012; Igwe 2015a; Igwe 2015b; Igwe and Una 2019 and Egbueri et al. 2020). Emeh et al. (2018), explained that pollution of soil also lowers its strength in withstanding erosion since pollutants impacts on the soil mineralogy during runoff processes, and such facilitates the potency of erosion.

From the review of cognate literature, southeastern Nigeria is profoundly affected by surficial geomorphic processes (Ofomata and Umeuduji, 1994) lubricated by intense precipitation (Eze, 2007) making the soils to be highly saturated during the rainy season. However, soil property is one of the major determinants of its response erosion processes. In our study area, critical works exist on the factors of soil erosion (Ofomata, 1985; Okoroafor, 2017), impacts of soil erosion on the species (Asuoha,2019), quantification and management of soil erosion in south eastern Nigeria(Okenmuo,2021) but less attention have been paid to the geotechnical characteristics of soil in south eastern Nigeria with special reference to the host rocks except for Igwe and Egbueri (2018). They discussed the erodibility potentials of soils in Benin, Ogwashi-Asaba and Nanka formations in Anambra state while the rest of the states in southeastern Nigeria underlain by weakly consolidated sediment formations were left in complete obscurity. We therefore considered it necessary to unravel the interplay of geotechnical attributes of soil in erosion processes occurring on weakly consolidated sediment formations in south eastern Nigeria. Thus, the knowledge sieved out from this research will be very useful in land use/ management, control of soil erosion and solving its associated problems in the tropics.

The Study Area

The study area is located within longitudes 06°40′ E - 07°40′ E and latitudes 06°00′ N - 07°00′ N of Anambra and Enugu state (Fig.1). The area falls within the humid tropical rainforest belt of south eastern Nigeria. Thus, the area have a significant record of rainfall fall values of 1500mm-2000 annually usually exhibiting double maxima and two minima yearly. In the first rainfall minima, its value is below 20mm during dry season in November to February while the second minimum occurs in August most called the little dry season (Anyadike and Phil-eze, 1989). Two distinguishable seasons of wet and dry season prevails. The mean annual sunshine hours are about 1750 hours with the mean annual temperature varying from 22°C to 28°C in the wet season and between 28°C and 32°C.

The relief of the study area is mostly undulating, typified by highlands and lowlands, with elevation range of less than 50meters to 591meters and vast area of the terrain is dissected by a plethora of rivers(Ofomata and Umeuduji, 1994). Concerning the vegetation, Igbozuruike(1975) described it as extensive savannah and rainforest region. Presently, the natural vegetation setting has been altered heavily due urbanization and man’s quest for survival. The modification of the vegetation land has exposed the landscape to vagaries of erosion forces.

Geologically, the study site is a composition of heterogeneous earth materials which includes beach sands, coastal plain sands, mangrove swamp deposits, sandstones, shale, sombrero deltaic deposits, recent and sub-recent alluvium (Fig. 1). The geologic underlay ranges from Campanian(cretaceous) to Eocene(tertiary) depositions with Nkporo and Ameki as the oldest and youngest sediment formations. Other formation in the study area such as Nanka sands in Ameki formation, Ajali formation and Nsukka formation are weakly consolidated are very susceptible to erosion and other surfio-fluvial geomorphic processes (Akpokodje et al., 1986; Okagbue, 1988; Nwajide, 1992; Akpokodje et al., 2010).

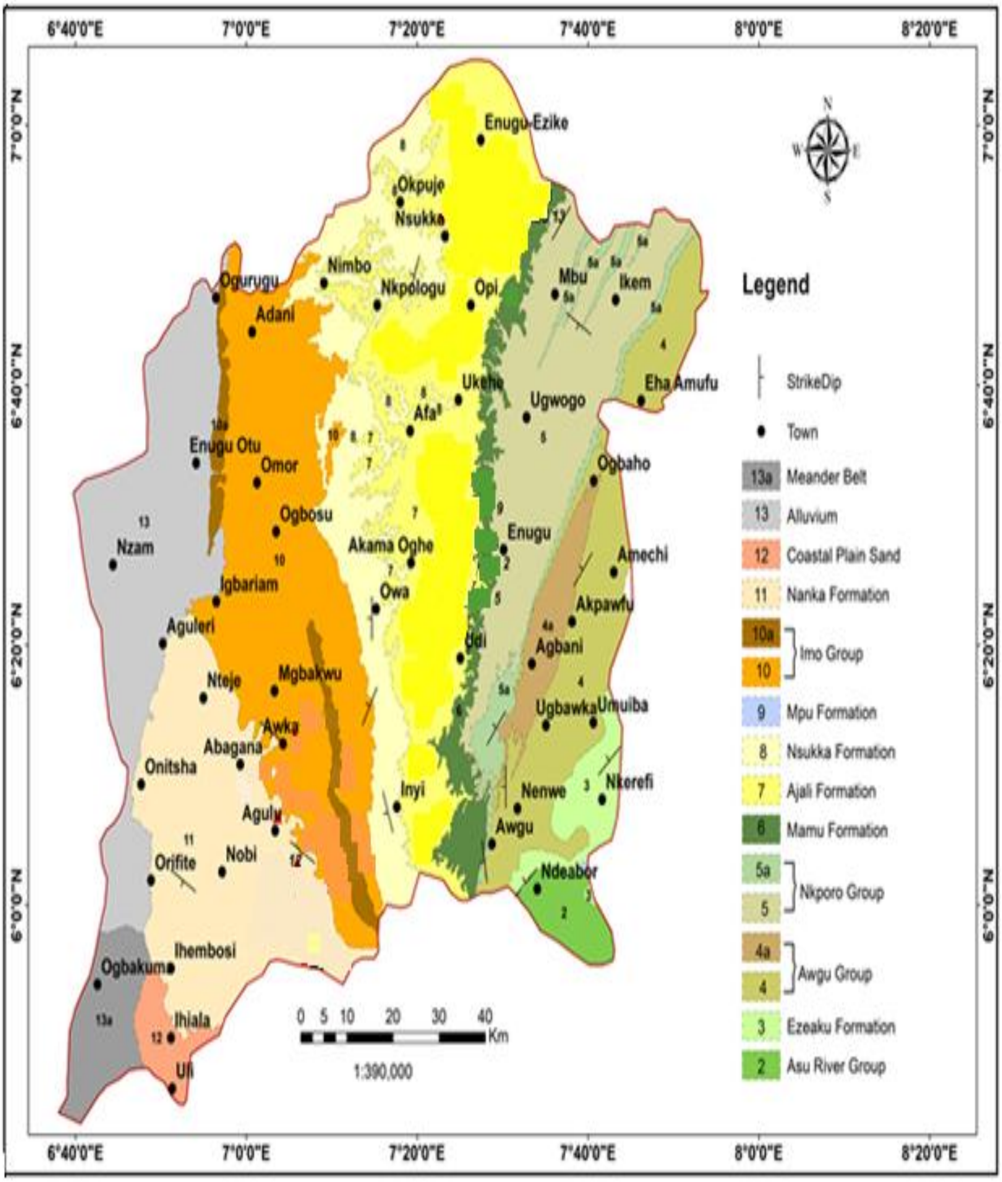

Fig: 1. The Location of the Study area.

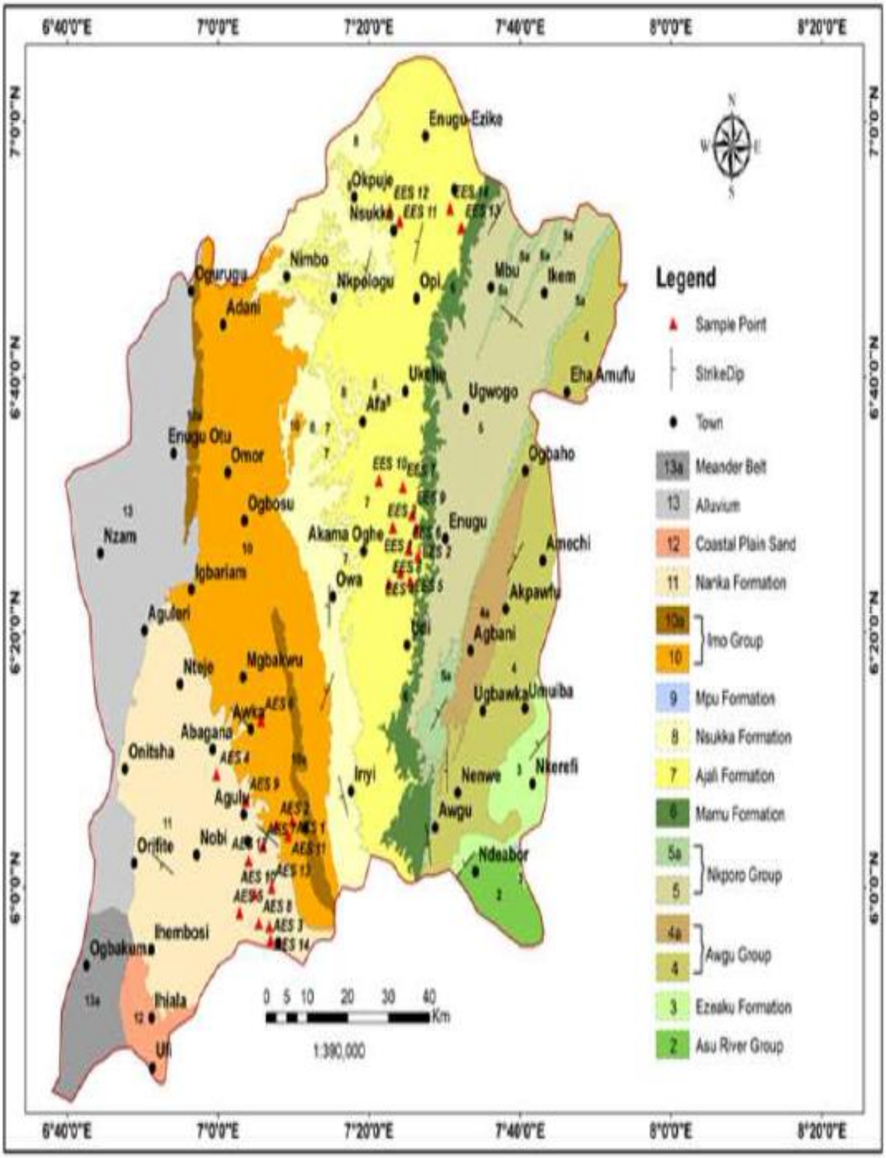

Fig.2: The Study area showing sample points.

Methodology

The analytical and experimental nature of this study required intensive field work and the application of laboratory apparatus on the soil samples collected from different points for analysis.

During the fieldwork, gully dimensions such as channel length (CL), channel width (CW), Channel depth (CD) and slope angle (SA) were logged. Soil samples were collected following custody of practices Kalinski (2011) on 28 erosion sites. Hand held auger was utilized in getting the soils within 2meters with minimal distortion of soil grain. The samples were collected during the rainy season viz- a-viz 3 days after rain so that the natural moisture condition of the soil will be retained. The samples were taken to the National Steel Raw Materials Exploration Agency’s laboratory, Kaduna, using relevant standard and established equipment within 96 hours after collection for laboratory analysis. The geotechnical tests carried out in the laboratory are sieve analysis, Atterberg limits; triaxial compression test, compaction, consolidation, specific gravity, coefficient of permeability (*k*), porosity and soil saturation tests in order to determine the soil particle size distribution, consistency limits- liquid limit (LL) and plasticity index (PI),shear strength parameters- cohesion (*c*) and internal friction angle (ϕ), natural moisture content (NMC), maximum dry density (MDD) and optimum moisture content (OMC), coefficient of consolidation (Cv) and coefficient of volume compressibility (Mv), specific gravity (SG), permeability(*k*), unit weight (ϒ), porosity (*n*)and bulk density (*ρ)* andsoil-water saturation (*S*) respectively.

Data Analysis

Data from the laboratory analysis were analysed through to Pearson correlation analysis in other to establish the relationship existing among parameters. Pearson correlation analysis of the data assisted us in determining the sampled parameters which occurred dependent or independent of each other. Thus, correlation analysis, showed the attributes which displayed a lot of interplay for the erosion processes to occur.

Result and Discussion

The Tables 1,2 and 3 contain the result of the correlation analysis.

Table 1: Correlation Matrix of the Soil Composition

	Gravel	Sand	Silt/ clay	*C*	ϕ	ϒ	LL	PL	PI	NMC	MDD
Sand	-.445*										
	.018										
Silt/clay	.260	-.981**									
	.181	< .001									
C	.364	-.892**	.882**								
	.057	< .001	< .001								
Φ	-.154	.877**	-.912**	-.776**							
	.434	< .001	< .001	< .001							
ϒ	.098	-.743**	.780**	.564**	-.689**						
	.620	< .001	< .001	.002	< .001						
LL	.266	-.932**	.946**	.849**	-.934**	.678**					
	.172	< .001	< .001	< .001	< .001	< .001					

PL	.029	-.448*	.476*	.344	-.380*	.505**	.438*				
	.884	**.017**	**.010**	**.073**	**.046**	**.006**	**.020**				
PI	.242	-.799**	.808**	.700**	-.667**	.668**	.717**	.815**			
	.214	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**			
NMC	.104	-.349	.354	.354	-.496**	.387*	.378*	.065	.144		
	.597	**.068**	**.065**	**.064**	**.007**	**.042**	**.047**	**.742**	**.464**		
MDD	.026	.682**	-.741**	-.644**	.728**	-.705**	-.735**	-.310	-.531**	-.512**	
	.896	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**.109**	**.004**	**.005**	
OMC	-.022	.252	-.267	-.197	.234	-.041	-.261	.127	-.133	.436*	-.051
	.910	**.196**	**.170**	**.314**	**.231**	**.836**	**.179**	**.521**	**.500**	**.021**	**.798**

***** Significant at .05; ** Significant at .01***

From Table 1, gravel composition marginally had a negative relationship with sand composition ($r = -.445$, $p = .018$), which was statistically significant. Sand composition was positively related with internal friction angle ($r = .877$, $p < .001$) and maximum dry density ($r = .682$, $p < .001$) and negatively related with silt/clay ($r = -.981$, $p < .001$), cohesion ($r = -.892$, $p < .001$), unit weight ($r = -.743$, $p < .001$), liquid limit ($r = -.932$, $p < .001$), plastic limit ($r = -.448$, $p = .017$), plasticity index ($r = -.799$, $p < .001$). These values show that sand impacts on erosion triggering soil parameters than erosion resisting properties. On the other hand, silt/clay influences erosion inhibiting soil attributes than erosion initiating soil factors by positively relating with cohesion ($r = .882$, $p < .001$) unit weight ($r = .780$, $p < .001$), liquid limit ($r = .946$, $p < .001$), plastic limit ($r = .476$, $p = .010$) and plastic index ($r = .808$, $p < .001$) and negatively related with internal friction angle ($r =.912$, $p < .001$) and maximum dry density ($-.741$, $p < .001$).

Cohesion was positively related with unit weight ($r = .564$, $p = .002$), liquid limit ($r = .849$, $p < .001$) and plasticity index ($r = .700$, $p < .001$) and negatively related with internal friction angle ($r = -.776$, $p < .001$) and maximum dry density ($r = -.644$, $p < .001$).Internal friction angle was positively related with maximum dry density ($r = .728$, $p < .001$) and negatively related with unit weight ($r = -.689$, $p < .001$), liquid limit ($r = -.934$, $p < .001$), plastic limit ($r = -.380$, $p = .046$), plasticity index ($r = -.667$, $p < .001$) and natural moisture content ($r = -.496$, $p = .007$).These findings suggest that soil particles' cohesion prevents erosion by improving soil plasticity and water contents while internal friction angle encourages erosion propagation by increasing soil water drainage.

Unit weight was positively related with liquid limit ($r = .678$, $p < .001$), plastic limit ($r = .505$, $p = .006$), plasticity index ($r = .668$, $p < .001$) and natural moisture content ($r = .387$, $p = .042$) and negatively related with maximum dry density ($r = -.705$, $p < .001$). Liquid limit was positively related with plastic limit ($r = .438$, $p = .020$), plasticity index ($r = .717$, $p < .001$), natural moisture content ($r = .378$, $p = .047$) and negatively related with maximum dry density ($r = -.735$, $p < .001$). Plastic limit was positively related with plasticity index ($r = .815$, $p < .001$). Plasticity index was negatively related with maximum dry density ($r = -.531$, $p = .004$). Natural moisture content was positively related with optimum moisture content ($r = .436$, $p = .021$) and negatively related with maximum dry density (r = -.512, p = .005).These numbers imply that soil water content increases its unit weight and plasticity which increase the soil resistance to erosion.

Table 2: Correlation Matrix of the Soil Composition Contd.

	Gravel	Sand	Silt/ clay	*C*	ϕ	ϒ	LL	PL	PI	NMC	MDD
SG	.249	-.787**	.794**	.734**	-.715**	.591**	.707**	.328	.674**	.180	-.620**
	.202	**<.001**	**<.001**	**<.001**	**<.001**	**.001**	**<.001**	**.089**	**<.001**	**.358**	**<.001**
Cv	.292	-.113	.058	.024	-.033	.124	.070	.124	.042	.277	-.156
	.131	**.568**	**.771**	**.904**	**.867**	**.529**	**.725**	**.528**	**.833**	**.153**	**.427**
Mv	.253	-.829**	.838**	.765**	-.780**	.651**	.802**	.355	.664**	.399*	-.720**
	.194	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**.064**	**<.001**	**.036**	**<.001**
P	.175	-.883**	.913**	.769**	-.899**	.728**	.924**	.329	.610**	.468*	-.785**
	.372	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**.088**	**.001**	**.012**	**<.001**
N	.429*	-.732**	.695**	.609**	-.629**	.560**	.683**	.297	.555**	.221	-.551**
	.023	**<.001**	**<.001**	**.001**	**<.001**	**.002**	**<.001**	**.125**	**.002**	**.259**	**.002**
S	.142	-.740**	.766**	.737**	-.785**	.429*	.729**	.324	.670**	.423*	-.555**
	.470	**<.001**	**<.001**	**<.001**	**<.001**	**.023**	**<.001**	**.092**	**<.001**	**.025**	**.002**
K	.461*	-.901**	.870**	.817**	-.686**	.643**	.757**	.493**	.875**	.134	-.522**
	.013	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**.008**	**<.001**	**.496**	**.004**
SA	.116	.622**	-.696**	-.568**	.665**	-.551**	-.697**	-.513**	-.646**	-.255	.685**
	.556	**<.001**	**<.001**	**.002**	**<.001**	**.002**	**<.001**	**.005**	**<.001**	**.190**	**<.001**
CD	.019	.531**	-.576**	-.590**	.575**	-.277	-.649**	-.229	-.407*	.031	.432*
	.925	**.004**	**.001**	**.001**	**.001**	**.154**	**<.001**	**.242**	**.032**	**.874**	**.022**
CW	-.077	.503**	-.525**	-.438*	.626**	-.329	-.720**	-.297	-.312	-.232	.436*
	.698	**.006**	**.004**	**.020**	**<.001**	**.087**	**<.001**	**.125**	**.106**	**.236**	**.020**
CL	-.116	.685**	-.713**	-.575**	.826**	-.487**	-.808**	-.176	-.388*	-.519**	.594**
	.557	**.000**	**<.001**	**.001**	**<.001**	**.009**	**<.001**	**.370**	**.041**	**.005**	**.001**

**** Significant at .05; ** Significant at .01***

From Table 2, gravel had a significant positive relationship with porosity (r = .429, p = .023) and coefficient of permeability (r = .461, p = .013). This observation signifies that gravel increases porosity and water flow in a soil, thus exposing the soil to excessive water saturation that encourages particle detachability and liquefaction (quick sand behaviour).

Sand was positively related with slope angle ($r = .622, p < .001$), channel depth ($r = .531, p = .004$), channel width ($r = .503, p = .006$) and channel length ($r = .685, p < .001$), and negatively related with specific gravity ($r = -.787, p < .001$), coefficient of volume compressibility ($r = -.829, p < .001$), bulk density ($r = -.883, p < .001$), porosity ($r = -.732, p < .001$), degree of saturation ($r = -.740, p < .001$) and coefficient of permeability ($r = -.901, p < .001$). Internal friction angle was positively related with slope angle ($r = .665, p < .001$), channel depth ($r = .575, p = .001$), channel width ($r = .626, p < .001$) and channel length ($r = .826, p < .001$) and negatively related with specific gravity ($r = -.715, p < .001$), coefficient of volume compressibility ($r = -.780, p < .001$), bulk density ($r = -.899, p < .001$), porosity ($r = -.629, p < .001$), degree of saturation ($r = -.785, p < .001$) and coefficient of permeability ($r = -.686, p < .001$).Maximum dry densitywas positively related with slope angle ($r = .685, p < .001$), channel depth ($r = .432, p = .022$), channel width ($r = .436, p = .020$) and channel length ($r = .594, p = .001$) and negatively related with specific gravity ($r = -.620, p < .001$), coefficient of volume compressibility ($r = -.720, p < .001$), bulk density ($r = -.785, p < .001$), porosity ($r = -.551, p = .002$), degree of saturation ($r = -.555, p = .002$) and coefficient of permeability ($r = -.522, p = .004$). These data revealed that sand content, internal friction angle and maximum dry density are the underlying factor in gully initiation and expansion in the region

Conversely, silt/clay and cohesion have an insignificant or no contribution in the increase of the gullies' geometry. Silt/clay was positively related with specific gravity ($r = .794, p < .001$), coefficient of volume compressibility ($r = .838, p < .001$), bulk density ($r = .913, p < .001$), porosity ($r = .695, p < .001$), degree of saturation ($r = .766, p < .001$) and coefficient of permeability ($r = .870, p < .001$), and negatively related with slope angle ($r = -.696, p < .001$), channel depth ($r = -.576, p = .001$), channel width ($r = -.525, p = .004$) and channel length ($r = -.713, p < .001$).Cohesion was positively related with specific gravity ($r = .734, p < .001$), coefficient of volume compressibility ($r = .765, p < .001$), bulk density ($r = .769, p < .001$), porosity ($r = .609, p = .001$), degree of saturation ($r = .737, p < .001$) and coefficient of permeability ($r = .817, p < .001$), and negatively related with slope angle ($r = -.568, p = .002$), channel depth ($r = -.590, p = .001$), channel width ($r = -.438, p = .020$) and channel length ($r = -.575, p = .001$).

Furthermore, unit weight was positively related with specific gravity ($r = .591, p = .001$), coefficient of volume compressibility ($r = .651, p < .001$), bulk density ($r = .728, p < .001$), porosity ($r = .560, p = .002$), degree of saturation ($r = .429, p = .023$) and coefficient of permeability ($r = .643, p < .001$), and negatively related with slope angle ($r = -.551, p = .002$) and channel length ($r = -.487, p = .009$). Liquid limit was positively related with specific gravity ($r = .707, p < .001$), coefficient of volume compressibility ($r = .802, p < .001$), bulk density ($r = .924, p < .001$), porosity ($r = .683, p < .001$), degree of saturation ($r = .729, p < .001$) and coefficient of permeability ($r = .757, p < .001$), and negatively related with slope angle ($r = -.697, p < .001$), channel depth ($r = -.649, p < .001$), channel width ($r = -.720, p < .001$) and channel length ($r = -.808, p < .001$). Plastic index was positively related with specific gravity ($r = .674, p < .001$), coefficient of volume compressibility ($r = .664, p < .001$), bulk density ($r = .610, p < .001$), porosity ($r = .555, p = .002$), degree of saturation ($r = .670, p < .001$) and coefficient of permeability ($r = .875, p < .001$), and negatively related with slope angle ($r = -.646, p < .001$), channel depth ($r = -.407, p = .032$) and channel length ($r = -.388, p = .041$).Plastic limit was positively related with coefficient of permeability ($r = .493, p = .008$) and negatively related with slope angle (r = -.513, p = .005). Natural moisture content was positively related with coefficient of volume compressibility (r = .399, p = .036), bulk density (r = .468, p = .012) and degree of saturation (r = .423, p = .025), and negatively related with channel length (r = -.519, p = .005).Therefore, soil unit weight, liquid limit, plastic limit and natural moisture content may also not be contributory factors to gully geometry increase and as such could be limiting erosion propagation in the study area.

Table 3: Correlation Matrix of the Soil Composition Contd.

	OMC	SG	Cv	Mv	*ρ*	*n*	*S*	*k*	SA	CD	CW
SG	-.258										
	.185										
Cv	.377*	-.103									
	.048	**.600**									
Mv	-.092	.649**	.247								
	.641	**<.001**	**.204**								
P	-.154	.704**	.115	.736**							
	.434	**<.001**	**.558**	**<.001**							
N	-.116	.682**	-.088	.427*	.656**						
	.558	**<.001**	**.655**	**.024**	**<.001**						
S	-.116	.776**	-.024	.645**	.673**	.581**					
	.557	**<.001**	**.905**	**<.001**	**<.001**	**.001**					
K	-.296	.777**	-.012	.686**	.685**	.701**	.725**				
	.127	**<.001**	**.951**	**<.001**	**<.001**	**<.001**	**<.001**				
SA	.079	-.423*	-.172	-.615**	-.711**	-.387*	-.479**	-.520**			
	.688	**.025**	**.382**	**<.001**	**<.001**	**.042**	**.010**	**.005**			
CD	.565**	-.492**	.236	-.417*	-.595**	-.295	-.366	-.409*	.564**		
	.002	**.008**	**.227**	**.027**	**.001**	**.128**	**.055**	**.031**	**.002**		
CW	.138	-.172	-.110	-.416*	-.639**	-.309	-.332	-.272	.488**	.561**	
	.483	**.381**	**.578**	**.028**	**<.001**	**.109**	**.085**	**.162**	**.008**	**.002**	
CL	.079	-.370	-.155	-.581**	-.831**	-.467*	-.583**	-.428*	.619**	.441*	.810**
	.691	**.053**	**.431**	**.001**	**<.001**	**.012**	**.001**	**.023**	**<.001**	**.019**	**<.001**

Significant at .05; ** Significant at .01

From Table 3, other parameters that may not have influential roles in the erosion advancement are specific gravity, soil volume compressibility coefficient and bulk density. Specific gravity was positively related with coefficient of volume compressibility (r = .649, p < .001), bulk density (r = .704, p < .001), porosity (r = .682, p < .001), degree of saturation (r = .776, p < .001), coefficient of permeability (r = .777, p < .001), and negatively related with slope angle (r = -.423, p = .025) and channel depth (r = -.492, p = .008). Coefficient of volume compressibility was positively related with bulk density ($r = .736$, $p < .001$), porosity ($r = .427$, $p = .024$), degree of saturation ($r = .645$, $p < .001$) and coefficient of permeability ($r = .686$, $p < .001$), and negatively related with slope angle ($r = -.615$, $p < .001$), channel depth ($r = -.417$, $p = .027$), channel width ($r = -.416$, .028) and channel length ($r = -.581$, $p = .001$). Bulk density was positively related with porosity ($r = .656$, $p < .001$), degree of saturation ($r = .673$, $p < .001$) and coefficient of permeability ($r = .685$, $p < .001$), and negatively related with slope angle ($r = -.711$, $p < .001$), channel depth ($r = -.595$, $p = .001$), channel width ($r = -.639$, $p < .001$) and channel length ($r = -.831$, $p < .001$).optimum moisture content had significant positive relationship with coefficient of consolidation ($r = .377$, $p = .048$) and channel depth ($r = .565$, $p = .002$).

Porosity was positively related with degree of saturation ($r = .581$, $p = .001$) and coefficient of permeability ($r = .701$, $p < .001$), and negatively related with slope angle ($r = -.387$, .042) and channel length ($r = -.467$, $p = .012$). Degree of saturation was positively related with coefficient of permeability ($r = .725$, $p < .001$), and negatively related with slope angle ($r = -.479$, $p = .010$) and channel length ($r = -.583$, $p = .001$). Coefficient of permeability was negatively related with slope angle ($r = -.520$, $p = .005$), channel depth ($r = -.409$, $p = .031$) and channel length ($r = -.428$, $p = .023$).With marginal relationships with gully geometry, soil porosity, saturation and permeability may not have a direct but indirect connection with gully expansion in the region.

Slope angle was positively related with channel depth ($r = .564$, $p = .002$), channel width ($r = .488$, $p = .008$) and channel length ($r = .619$, $p < .001$). Channel depth was positively related with channel width ($r = .561$, $p = .002$) and channel length ($r = .441$, $p = .019$), while channel width was positively related with channel length ($r = .810$, $p < .001$). These relationships suggest that all these gully attributes may be contributing in the same way in erosion propagation in the study region.

In summary, the above results indicate that increase in sand size particles facilitates the erodibility of soil since, sand correlates positively with gully geometry (i.e slope angle, gully depth, gully width and gully length). Furthermore, the higher the silt/clay particles of soil, the lower its erodibility since silt/ clay relates negatively with slope angle, gully depth, width and length. Concerning soil consistency (liquid limit and plasticity index) and soil strength (cohesion) play major roles in erosion retardations. The higher the soil plasticity is, and the strength, the lower the erodibility of the soil. Conversely, the denser a soil, the lower the rate of erosion propagation since bulk density correlates negatively with gully geometry such as the slope angle, gully depth, length and width.

The result of the research has shown that erosion is inevitable in south eastern Nigeria and will continue to occur at varying capacity because of the non-uniform indices of the geotechnical attributes of the soils. Hence, there is so much sand in the region coupled with the heavy intensity and duration of rainfall which favours surficial geomorphic processes thereby making the landscape of southeastern, Nigeria very susceptible to erosive forces. This is in agreement with Igwe and Egbueri (2018) on characteristics and erodibility potentials of soils from geologic settings of Benin, Ogwashi-Asaba and Nanka in Anambra State.

Therefore, having unravelled the soils from extensive formations of south eastern Nigeria, we zero in that soil geotechnical composition is a major integer in erosion processes especially gullying in our region.

Conclusion

This study investigated the interplay of geotechnical parameters of soils of the weakly consolidated sediment formations in erosion occurrence in southeastern Nigeria. A total of 28 massive gully erosion sites were documented and sampled in the region during the fieldwork. In the study, Pearson correlation model was employed to better understand the relationships between gullible soil geotechnical attributes.

Pearson correlation data revealed that there is a strong negative relationship between sand and silt/clay (fines) contents in the gully soils. The statistical model also showed that while the sand content is positively related to erosion enhancing soil properties and gully geometry such as internal friction angle, gully depth, gully width and gully length and negatively correlating with erosion impeding soil characteristics like cohesion, liquid limit, plasticity index and bulk density, the reverse is the case with silt/clay contents. Silt/clay was observed to be negatively related to internal friction angle, slope angle, gully depth, gully width and gully length, but positively related to cohesion, liquid limit, plasticity index and bulk density. These results imply that both sand and silt/clay contents play different important roles in erosion development in the region, and the higher percentage of the former or the later determines respectively the vulnerability or resistance of a soil to erosion and gullying process. Finally, the authors suggest that findings in the study should be incorporated by environmental planners and earth scientists into long-term management plans for southeast and other regions prone to severe erosion.

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