Geotechnical Evaluation of Gully Erosion and Landslides Materials and their Impact in Iguosa and its Environs, Western Anambra Basin, Nigeria.

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Research

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Abstract

Background: Field survey and geotechnical evaluation was done to determine the soil characteristics of the gullies and landslides materials and their impact in Iguosa and its environs, Western Anambra Basin. This was done to explain and evaluate the root problems, causes, mechanism of the continuous gullies and landslides in the study area.

Results: The field study reveals that the geomorphological characteristics, weakly developed structures, slope steepness, wrong use of the land and poor vegetation cover coupled with intense and prolonged rainfall contributed to the origin, causes of gullies and landslides in the study area. Geotechnical parameters for soil samples in the study area shows that the mean liquid limit (LL) of 40, mean plastic limit (PL) of 8.30, mean plasticity index (PI) of 21.20, mean coefficient of permeability (K) of 3.65 × 10cm/sec, mean cohesion and mean angles of internal angles between grains of 2.56 k□a and 23.7^0 respectively. The low PL, low LL and low PI values of the Ajali sand, low cohesion (poor compaction) and low angle of internal resistance between grains of the soil, high K of Ajali sand coupled with the swelling and shrinking nature of the clay beds beneath the Ajali sand, resulted to easily weathering of the Ajali sands, erosional and continuous landslide activities in these affected areas.

Conclusions: The origin, mechanism and impacts of landslide hazards have been investigated in Iguosa and its environs, Western Anambra Basin, Nigeria. Field observation reveals that the geomorphological characteristics, weakly developed structure, high slope instability, wrong use of land, as well as the steepness of the slope and intense and prolonged rainfall contributed to the origin of landslide as well as the gully erosion in the study area. The unconsolidated nature of the soil, less cohesion, high permeability, and weak plasticity of the soil that occurs under and above the clay lithologic units (gliding planes) contributed to landslide and gully erosion. Possible prospective implications of the gully erosion and landslides in the study areas are land degradation, destruction of houses and other properties, farm lands and roads. The following suggestions have been made to solve these problems by covering the landslide areas with impermeable layers/materials, diverting surface water away from the landslide areas, enacting laws to prevent erection of structures on landslide prone areas, the use of biotechnical slope techniques and bioengineering methods. The application of these recommended methods will go a long way in solving the problem of landslide hazards in the study area.

Background

Landslides are a major landscape disaster in Africa that has damaged properties worth millions to billions of dollars annually during the rainy seasons (Igwe 2015). The mechanisms of rainfall induced landslides have been extensively studied (Iverson 2000; Msilimba and Holmes 2010; Wang et al.2002; Sassa et al., 2004; Guzzetti et al. 2008; Igwe 2015; Igwe and Una 2019). The amount of rainfall, degree of slopes, discontinuities and weathering are the major factors predisposing landslides. Intense and prolonged rainfall coupled with flooding has continued to trigger landslides and gully erosion around the globe. In West Africa countries, landslides are caused primarily by rainfall (Igwe 2015). The prolonged rainfall of October 2013 initiated twenty-eight (28) new shallow landslides and gully erosion in Enugu and four pronounced landslides and gully erosion at Obudu area of Calabar which resulted to casualties, severe economic loss, etc. (Igwe 2015). The type of slope materials in high elevation areas coupled with torrential rainfall results to gullies and landslides of various forms and sizes in Enugu State (Igwe 2015). In Nigeria today, the frequencies and variations of landslides and erosional activities are mostly controlled by geological settings. The poor drainage systems in the study area cannot withstand the excess runoff during the rainy seasons. The excess water flow is trapped in narrow concentrated streams which latter create wide erosive channels in the earth surfaces, thereby creating gullies of various forms, scales and different sizes. These gullies gave rise to multiple slope failures, land degradation, loss of buildings, and property worth billions of dollars. The proper understanding of the mechanism of precipitation- induced landslides is relatively lacking in the study region. Also, these damaging hazards are not systematically monitored in Nigeria (Igwe 2015).

Good research works in Nanka and other part of Southern Eastern Nigeria in Anambra Basin concerning landslides and gully erosion have been well documented in the work of (Okagbue 1992; Ogbukagu 1976; Egboka and Okpoko 1984; Igwe 2013; Igwe 2015). The nature of landslides in Nanka area according to (Okagbue 1992) occur occasionally in translational pattern. The clay beds demarcating the lower sand horizon acts as the gliding plane for several large slumps (Ogbukagu 1976; Okagbue 1986). Many slumps in the area are known to occur within the near homogeneous soil overburden (Okagbue 1992). Slope failures in Nanka are usually frequently during short or long, intense rainfalls which usually take place at the beginning of rainy season. The upshot of high pore water pressures generated by rainfalls during the rainy season and the swelling characteristics of clay minerals in interbedded clay/ shale units have been stated as the mechanism of landslides in Nanka (Egboka and Okpoko 1984; Okagbue 1992). Impacts of landslides in Nanka Landslides have impacted Nanka area negatively.

Slope angle is an important parameter in estimating susceptibility to developing rock/soil sliding activities globally which may range from gentle to very steep slopes depending on the angle of displacement between the vertical rock wall and the horizontal rock floor. Sikdar et.al 2004 worked on Raniganj coal mining area of Western Bengal and the slopes within study area varies between 0^0 to 15^0 ie very gentle to moderate slope. They were able to classify slopes based on their classes, symbols and descriptions in Table 1 (Sikdar et.al 2004). (Chen et al. 2012a, b) identify slope failure that comes after the 2008 Wenchuan earth quake take place majorly on slopes angles range of 30^o-50^o. (Koko et al. 2005) had similar observations that the hazards and risk correlated with rainfall induced landslide along railway occurs at high slope angles of ($32^o - 42^o$) of stratigraphic sequence of layers of sand materials overlying thin shale/clay stone materials because of the mineral composition of clay stone / shale which absorb a lot of water during rain fall and expands its volume. The increase in the volume will create an upward force on the overlying sand layers. The alternation of swelling and shrinking during the rainy and dry seasons respectively, thereby giving rise to slope failures.

Table 1
Class and description of slopes (Sikdar et.al 2004)

No	Class	Symbol	Description
1	0^0 to 5^0	A	Very gentle
2	5^0 to 10^0	B	Gentle
3	10^0 to 15^0	C	Moderate
4	15^0 to 25^0	D	Moderately steep
5	25^0 to 35^0	E	Steep
6	$> 35^0$	F	Very steep

When there is torrential rainfall, soil is totally saturated, soil matric suction will cease to be visible completely and a perched water table with pore-water pressure will develop in the soil, this will lead to a decrease of the shear strength of the soil due to increase in pore-water pressure and loss of soil apparent cohesion, this will as a result trigger landslides (Fukuoka 1980; Wieczorek 1996; Li et al. 2005; Lee et al. 2012; Igwe et al. 2013). Brand et al. (1984) is of the opinion that most of landslides and erosional activities in Hong Kong were rainfall induced either as (concentrated, short-duration rainfalls of high intensity).

The mitigation measure for the impacts of landslide and gully erosional activities are discussed below: Highland and Bobrowsky (2008) stated that sufficient drainage systems are very important in the prevention of sliding or existing failure in a study area. According to Gray and Sotir (1996); biotechnical slope protection techniques comprises biotechnical stabilization and soil bioengineering stabilization which both make use of vegetation. Gray and Leiser (1982) reported that biotechnical stabilization method make use of mechanical elements coupled with biological elements to avert and stop slope failures and erosion. Bamboo trees have been successfully used to stabilize slopes in some parts of Oko and Amucha in Southeast Nigeria (Igwe and Una 2019).

Conventional understanding of the root cause and continuous land sliding in previous studies are inadequate. Several methods adopted by controlling landslides hazards and its root cause in Nigeria is ineffective because mass sliding is now a re-occurring decimal in the country. This rapid and devastating effects of landslides in the country have necessitated the field investigation and laboratory analysis of soil samples so as to provide detailed information about the root cause, mechanisms and the continuous mass sliding in the study area. This study aims to identify the root causes, mechanisms and impact of landslides in the study area since little or no work has be done in the study area and also recommend appropriate designs to mitigate future occurrence of this disasters in the study area. This research paper was able to examine these aspects, root problems, the mechanisms and proffer effective mitigation measures of the landslide disaster in the study area.

Location And Geology Of Study Area

The study area is within the Benin Flank, Western Anambra Basin and lies between latitudes 6^{O} 20^{1}N and 6^{O} 50^{1}N and longitudes 5^{O} 40^{1}E and 5^{O} 00 ^{1}E respectively (Figs. 1 and 2).

The geology of the study area is mainly characterized by the quaternary deposits, Benin Formation, Ajali Formation and Ogwashi - Asaba Formation. The Benin Formation comprises of top reddish to brown earth (laterite), underlain by sands, clay, very coarse to coarse, very poorly to poorly sorted sands and sometimes ferruginized sandstone, gravels and netlike mud cracks. The thickness ranges from 800m thick around Benin City and 1830m towards the sea (Obaje, 2011; Ikhile, 2015). The environment of deposition is mainly continental (Short and Stauble, 1967; Eva my et.al., 1975; Weber and Daukoru, 1978). The red earth sand is coastal plain environments which are exposed in Owerri, Calabar, Onitsha and Benin Region. The age of the Benin Formation ranges from Oligocene to Pleistocene.

The Quaternary deposits of the study area are mainly alluvium deposited on the flood plains of Ovia and Ikpoba. They are mostly reddish to brownish-white sands, silts, clayey sands and gravels.

The Ajali Formation dips $2–6^{0}$ in the Southwest direction. The Ajali Formation is mainly characterized predominantly by medium to coarse, friable, poorly sorted and poorly cemented sandstone banded by iron stain. The Ajali Formation is overlain by reddish sand usually formed by changes due to weathering close to the surfaces (Onwuemesi, 1990). The Ajali Formation because of low force of cohesion can easily be weathered compared to the overlying red sand which contain some presences of clay due to its force of cohesion.

Ogwashi–Asaba Formation: The Asaba–Ogwashi Formation is characterized by gritty sands, clay and seam of lignite with clay intercalations. It is exposed at the stream channels of the Northern part of Benin area towards the west of Ekiadolor- Iwu, Utekon, North Azalla (Akujieze, 2004).

Climatic Condition

The climatic condition of the study area have two distinct seasons which are the raining and the dry season. The raining season begins in April and stops in October while the dry season begins in November and ends march year in and year out. The study area by Nimet 2010; Ukhurebor and Abiodun 2018 have total annual rainfall range of about 1600mm – 2220mm. The mean monthly temperature during the raining season ranges from 20^{0}C – 28^{0}C and mean monthly temperature during the dry season ranges from 28^{0}C – 33^{0}C respectively. The area of study lies within tropical rainforest and characterized by trees and shrubs.

Methodology

Field Survey

Detailed field mapping and geotechnical survey were done to identify landslides areas, gullies, geological conditions, land cover map, slope angles and anthropogenic factors to determine the root cause of the problem, mechanism of the sliding, continuous and prolong land sliding in the study area. The landslides types were classified in accordance with (Varnes 1978; Crudes and Varnes 1996; perucca et. al 2009). The landslide locations are identified and interpreted from aerial photographs and field surveys. The depth, length, width, lateral extent of the slides were measured using measuring tapes. The slope angles and the elevations of the study areas measured with a Clinometer and Global Positioning System (GPS) respectively. The GPS was also used in producing the land use map/land cover map. The digital elevation models (Fig.3), land cover map, slope map for the study area were generated from the National Aeronautics and Space Administration (NASA) of 30m –data Spatial Resolution and Shuttle Radar Topographic Mission (SRTM). This will in turn help to show the effect of slope, elevations, and land use cover on the initiation, mechanisms and evolution of the landslides in the study areas (Fig.3). Each soil samples were collected randomly in the study area by driving the hand auger to a plough depth of 15cm to draw the soil samples. These random samples were collected from the top soil (15cm) by removing the top soil, slide walls and the slide floors respectively. Each collected samples were properly labelled, wrapped carefully with newspapers and placed in each polythene bags before taking them to the laboratory for further analysis.

Geotechnical Analyses

A set of British Standard sieve of various diameter 4.875mm, 3.55mm, 2.36mm, 1.18mm, 600um, 425um, 300um, 150um, 75um with a receiver pan for carrying out the sieve analysis was employed. The atterberg limit test was done to determine the lead characteristics of the soil. The atterberg limit comprise; liquid limit test which was done in accordance to the (British Standard 1990; Ishaquel et al. 2010). The plastic limit test was done according to (British Standard 1990; Ishaquel et al. 2010) and British Standard Testing Method for soil (B.S 1377-1990). The lead soil characteristics for the very finer grain sizes were determined using the hydrometer method. The triaxial tests were determined according to (B.S 1377 - 1990).The results obtained from the triaxial tests were plotted on a Mohr stress diagram (Mohr View) to determine the values for cohesion and angle of internal resistance respectively. The permeability of the soil was determined by the falling head method and constant head permeability test in accordance to (BS 1377.5: 1990; Munch and Douglas 1985).

Results And Discussion

Result of the field study

From Table 2, the result of elevation of the gullies and slides range from 22.86m to 332.0m with mean elevation of 183.11m of the landslides and gullies. The angle of slope of the slides (slope steepness) ranges from 7^0 to 32^0 with mean slope angles of $20.25^0$and these slope angles which are key parameters in estimating susceptibility to developing debris rock slides in the study area. The slopes angles range of 7^0 to 32^0indicate that the slope angles fall under the class of gentle to steep slope (Sikdar et.al 2004). The field result shows that the largest occurrences of landslide in the study area fall within an interval of slope angles ranging from 16^0 to 32^0. The slope angle of 32^o which indicates a steep slope (Tables 2 & 3, Figs. 4 & 5) where the largest occurrence of landslides falls in the field coupled with high elevation of 330m with mean elevation of 183.11m respectively have contributed immensely to the high instability of the soils in the study area. This has resulted to landslide and gully erosion and this support the work of (Koko et al., 2005; Chen et al., 2012a, b; Igwe 2015). Slope angles of 32^o at high elevation values measured in this work, correlates with the works of Chen et al. (2012a, b) and Koko *et al*. 2005. Chen et al. (2012a, b) identified slope failures that occurred after the 2008 Wenchuan earth quake, took place majorly on slope angles range of 30^o -50^o.. Koko et al. (2005) had similar observations that the hazards and risk correlated with rainfall induced landslide along railway occurs at high slope angles of (32^{o} – 42^{o}). This high slope values and elevation of the landslide and gullies in (Fig. 4, Table 2) the area is the cause of the mass sliding activities that are prominently trending in the northeast direction in the study area.

Table 2
Field measurements for gullies and slides in the study area

S/N	Longitudes (E)	Latitudes (N)	Elevations (m)	Lateral extents (m)	Depth (m)	Width(m)	Slope Angle (^{0})	Description of slope(Sikdar et.al 2004)
1	04^0 51' 23"	$06^0$30'4"	332.00	80.0	68.7	23.2	32	Steep slope
2	$04^0$05'43"	$06^0$27'41"	310.80	40.2	68.2	20.4	31	Steep slope
3	04^0 43'16"	$06^0$28'32"	306.00	80.0	66.9	28.4	20	Moderately steep slope
4	04^0 48' 10"	$06^0$28'30"	200.40	73.0	66.3	31.6	18	Moderately steep slope
5	04^0 12'13"	$06^0$24'00"	120.00	64.0	64.7	30.4	16	Moderately steep slope
6	04^0 13'13"	$06^0$04'14"	118.60	93.0	67.0	33.8	13	Moderate slope
7	05^0 32'07"	$06^0$32'00"	58. 40	69.4	67.1	33.7	10	Moderate slope
8	05^0 12' 18"	$06^0$37'01"	26.30	80.2	20.3	72.6	09	Gentle slope
9	05^0 03' 00"	$06^0$37'00"	24.70	50.2	4.1	46.7	07	Gentle slope
10	05^0 13' 00"	$06^0$27'01"	22.86	43.0	2.6	30.4	07	Gentle slope
11	05^0 32'13"	$06^0$24'00"	120.00	64.0	60.7	40.4	16	Moderately steep slope
12	$04^0$13' 23"	$06^0$34'14"	118.60	93.0	65.0	34.8	13	Moderately steep slope
13	05^0 44 16"	$06^0$28'32"	306.00	80.0	66.9	28.4	20	Moderately steep slope
14	05^0 42' 10"	$06^0$28'30"	200.40	73.0	64.3	32.6	18	Moderately steep slope
15	05^0 52'13"	$07^0$34'00"	120.00	64.0	64.7	32.4	16	Moderately steep slope
16	05^0 51' 19"	$06^0$37'40"	332.0	80.0	60.7	24.2	32	Steep slope
17	05^0 55 20"	06 37'41"	310.80	40.2	68.4	20.4	31	Steep slope
18	$05^0$53' 16"	06 38'32"	308.00	80.0	66.9	30.4	32	Steep slope

S/N	Longitudes (E)	Latitudes (N)	Elevations (m)	Lateral extents (m)	Depth (m)	Width(m)	Slope Angle (^{0})	Description of slope(Sikdar et.al 2004)
19	05^0 54’10”	$06^0$38’30”	204.40	73.0	64.3	32.6	32	Steep slope
20	05^0 55’13”	$06^0$40’00”	122.00	64.0	63.7	30.4	32	Steep slope
			MEAN = 183.11	MEAN = 87.30	MEAN = 57.07	MEAN = 32.24	MEAN = 20.25	Remarks:Gentle – Steep Slope

Table 3

Frequency of slope angles of the slides and gullies

Slopes Angles of the landslides (^{0})	Frequency of the landslides
70	2
90	1
10^0	1
13^0	2
16^0	3
18^0	2
20^0	2
31^0	2
32^0	5

The lateral extent ranging from 40.2 to 93.0m with mean lateral extent of 87.30m. The depth of slide ranging from 2.6m to 68.7m with mean of 57.07m and width value ranging from 20.4m to 72.6m with mean of 32.24m, indicate a high degree of erosion and sliding in the study area. The generated digital elevation model, slope map and land use map of the study area from 30m data -Spatial Resolution and Shuttle Radar Topographic Mission (SRTM) are shown (Figs. 3, 4 above and Fig. 6 below respectively). It shows that the elevation, the steepness of the slope, excess run off from heavy down pour and infiltration, deforestation, over grazing and the improper use of the land from the land cover map and poor drainage system contribute to the landslides and the exposure of the study area to other landslide related hazards in the study area. From the plot of the dimensions of the landslide against the slope angles of the landslide (Fig. 7), it shows that in this year the lateral extent and slopes angles of the landslides and gullies are sliding at almost the same rate in the north east direction in the field. During the early stage of gullying activities and sliding, the lateral extent of the slides and width of the slides were not proportionate. As the landslides and gullies become rapid this year, the lateral extent of the sliding become relatively proportional to the slope angles of the landslides (Fig. 7). The sliding in the area ranges from gentle to steep slopes at angle of 7^0 – 32^0 and the slides are trending in the north east direction in the study area (Figs. 8a & b). From Fig. 8b the blue colour shows initial stage of the sliding as very gentle to gentle slope. The red colour shows the advance stage of the sliding as moderately steep slope to steep slope in the study area. As the width of landslides increases, the lateral extent of the landslides increases relatively and these occur more on the mean slope angles of 22.5 ^{o} at mean elevations of the landslides and gullies of 183.11m. The lithology investigated in the field are upper most layer (dense lateritic soil), Ajali Formation and some clay materials at the slide walls and floor of the slides/gullies. The upper most layer is mostly of red earth with little clay material present. The Ajali Formation is characterized of medium to coarse grained, friable, unconsolidated to consolidated sands of 250cm thick in the landslides area. Also, within the landslide areas the units are interbedded by clay and fine materials.

Result of geotechnical analyses

The soil samples (table 4) from the landslides and gullies areas shows that soil samples SB1, SB2, SB6 and SB7 are mainly sandy clay with a plasticity indices of 30-36, coefficient permeability range of 3.5 $\times 10^{4-}$cm/sec – 4.2 $\times 10^{4-}$cm/sec, cohesion range of 27kPa - 28kPa and angle of internal resistance range of 27^{o} - 30^{o} respectively. Soil samples SB3, SB4, SB8 and SB9 are coarse-grained sand with no plasticity indices. The coefficient of permeability for samples SB3, SB4, SB8 and SB9) range of 2.8 $\times$ 10^{4-}cm/sec–3.2 $\times 10^{4-}$cm/sec, cohesion 10kPa - 18kPa with angle of internal resistance of 24^{o}- 26^{o} respectively. Soil samples SB5 and SB10 are silty clay with plasticity index range of 40 - 41, coefficient of permeability of 4.6 $\times$ 10^{4-}cm/sec - 4.8 $\times 10^{4-}$cm/sec, cohesion of 45kPa - 46kPa and angle of internal resistance of 10^{o}-12^{o} respectively. Soil samples (SB) 3, 4, 8 and 9 are non-plastic and they have liquid limits (LL) range of 24–26 with mean Liquid limit of 40 in the study area. The plastic limits (PL), liquid limit (LL) and plasticity index (PI) of SB5 and SB10 are 36 and 35, 76 and 76, 40 and 41 respectively. Plasticity index of 40 is high in the study area and this falls within the range of findings of Sowers and Sowers (1970). They reported that PI > 31 should be considered high and this indicates high content of expansive clay. SB5 and SB10 have liquid limit values of 76 and this conforms to the findings of Bell (2007), who classified clays with Liquid Limit (LL) range of 70– 90 as very high plasticity. The high plasticity values of 76 in SB5 and SB10 which are mainly of silt to clay layers because of their mineral composition will absorb a lot of water from rain fall and expand its volume within the slide and the gullies areas. The increase in the volume will create an upward force on the overlying coarse sand and medium sand layers. This alternating sequences of swelling and shrinking during wet and dry seasons will in turn give rise to the initiation of slopes failures and landslide activities in the study area. This has been able to explain the mechanism and root cause of the problem in the area. This may possibly explain why the clays in this area serve as glider/gliding plane to several landslides (Figs.9a&9b). In addition the very low permeability of silty clay units (SB5, SB10) that separates the sand units in the area have been identified to be the gliding plane for several landslides in the area of study (Okagbue 1992).

The cohesion values in the study area ranges from 10-40kPa with a mean value of 25.6kPa. The angles of internal resistance within the grains ranges from 10^{0}- 30^{0} with mean of 23.7^{0}. The low cohesion values of 10kPa with mean cohesion of 25.6kPa suggest a low cohesion between the grains (a very loose compaction). The mean value of angles of internal resistance between the grains in the area is 23.7^{0}. This low value suggest very loose compaction (Surenda and Sajeev 2017). They classified angles of internal resistances between grains as follows: < 28^{0} shows a very loose compaction, 28^{0}-30^{0} displays loose compaction, 30^{0}-36^{0} indicates a medium compaction, 36^{0}- 41^{0} indicates dense compaction, > 41 shows very dense compaction. The low values of cohesion and angles of internal resistances resulted to cracks, fractures and slopes of various degree in study area. The non-plastic characteristics of the Ajali sands which display a very loose to loose compaction in the study area increases its susceptibility to erosion and landslides.

The permeability values range from $2.6 \times 10^{4-}$cm/sec - $4.8 \times 10^{4-}$cm/sec with mean permeability of $3.65 \times 10^{4-}$cm/sec in the Ajali Formation which is labelled (SB3, SB4, SB8, SB9) in the study area. The high permeability values of range $2.6 \times 10^{4-}$cm/sec – $3.2 \times 10^{4-}$cm/sec in the Ajali Formation depicts a high permeability due to non-plasticity of the Ajali Formation in the study area. The high permeability values shows that the Ajali Formation in the study area (Fig.10a &b) transmits enough volume of water to the underlying SB5 and SB10 (silt/clay layers) during period of raining season. Within this sand- clay boundary a high pore-water pressure will be developed. This excess water will be release at the boundary from the clay (Fig.9a) because of low permeability values of $4.6 \times 10^{4-}$cm/sec - $4.8 \times 10^{4-}$cm/sec from SB5 and SB10 (Igwe and Una 2019). The increase in the volume of water is as a result of rainfall in the study area which will in turn create an upward force on the overlying coarse Ajali Formation. Due to wet and dry seasons experience in the study area it will give rise to swelling during wet period and shrinking during dry season. This continuous alternation of swelling and shrinking will initiate cracks, fractures and landslides in the study area (Fig.11) and this corroborate the work of (Fukuoka 1980; Wieczorek 1996; Igwe et al. 2013; Ogbukagu 1976; Okagbue 1986; Egboka and Okpoko 1984; Okagbue 1992). This has been able to explain the mechanism behind the continuous sliding and gullies in the area. The nature of the Ajali Formation which is friable, highly porous, unconsolidated, prone to rapid disintegration, low shear strength (low cohesion and low angles of internal resistances between the grains), low plasticity of Ajali Formation coupled with high rainfall in the study area over the years resulted in the multiple slope failures and debris soil slide and spread in the study area (Figs.12a,b &13) using the classifications of (Varnes 1978; Crudes and Varnes 1996; Jakob et. 2006; Guzzetti et al. 2008) .

Discussion

The study area is influenced by its geotechnical, geomorphological, geological and socio-cultural settings. The slopes of these areas are covered with green vegetation during the raining season and almost entirely bare due to overgrazing and drought during the dry season. Intense rainfall with high rate of infiltration/ excess run-off and soil erosion during the raining season in the study area weakens the slopes by detaching the lateral base of the soil thereby resulting to further steepening of the slopes (Appendix 1). The nature of the slope materials, soil characteristics, slope steepness and heavy rainfall are linked to the causes of gullies and landslides of various magnitudes in theses affected areas. The annual rainfall of the study area ranges from 1600mm to 2220mm (Ukhurebor and Abiodun 2018) and the slopes are initiated on the friable, weak sands interbedded with clay/silt materials. This is in agreement with the findings of other researchers (Igwe 2015; Igwe and Fukoka 2010). These characteristics of the soil and slope material coupled with the high annual rainfall have resulted to a very high slope instability associated with the gullies of various magnitudes in these affected areas. Most of the gullies/landslides identified in these areas have depths and slopes steepness ranging from > 2.5m to > 7^0 respectively. The geotechnical parameters of these affected areas revealed their susceptibility to gullies and continuous land sliding of various magnitudes.

The digital elevation model, slope map, land cover map generated from NASA SRTM 30m data shows exactly the impact of elevation, slope and vegetative/land cover on the root causes, problems and continuous expansion of the gullies and landsliding in the study area.

Detailed field mapping, geotechnical parameters evaluated such as liquid limit (LL), plastic limit (PL), plasticity index (PI), cohesion, frictional angles between grains and permeability (K) values of the soils shows the prevailing geological conditions and geotechnical characteristics of the soils. The high permeability, low cohesion and frictional angles between grains and non-plasticity of the Ajali sands are among the factors responsible for the initiation of slope failures. This also account for the formation of new steeper slopes, gullies, cracks as well as weathering of the soil and further expansion of the gullies and landslides in these areas. The low plasticity and low shear strength of the soils in the study area was also deduced by other researchers within the same Anambra basin (Onwuemesi 1990; Ocheli et al. 2021).

The high plasticity values of soil sample SB5 and SB10 will result in swelling and expansion of the clay/ silt materials in the study area upon heavy precipitation and resultant runoff and infiltration. The increase in the volume will create an upward force on the overlying coarse sand and medium sand units. This alternating sequences of swelling and shrinking during wet and dry seasons will in turn give rise to the initiation of slopes failures, creating new steep slopes at the base of the Ajali sand and further landslide activities in the study area. This explains the mechanism and root causes of the problems in the affected areas. In addition the very low permeability of silty/ clay units (SB5, SB10) that separates the sand units in the area have been identified to be the gliding plane for several landslides in these areas and this corroborate the works of (Ogbukagu 1976; Okagbue 1986; Egboka and Okpoko 1984; Okagbue 1992). This may possibly explain why the clays in this area serve as gliders/gliding planes to several landslides in the area.

From the findings above, over four hundred (400) houses, farm lands, landed property have been damaged and abandoned as well as other properties worth millions to billions of dollars (Figs. 14–15). The following suggestions have been made to solve these problems:

1. The slopes should be improved by drainage control and slope flattening. This reduces the weight of the mass tending to slide, providing a support below the toe and this support also increases the resistance to sliding and hence increases the stability (Egboka et al. 2019)
2. The landslide areas should be covered with impermeable layers/materials and also diverting of surface water away from the landslide areas.
3. Biotechnical slope method according to (Gray and Sotir 1996) should be employed to avert and stop slope failures and erosion by planting different plants on sloping landscape by government and individuals so as to stabilize the slope.
4. There should be construction of gravity and earth dams to channel the flood and this will help to reduce the velocity of inflows and convey large inflow of water away from different catchments areas around Ovia North-East into nearby stilling basins or Neighboring Okhoro River.
5. Federal, State and Local governments should enact laws to prevent erection of structures on landslide prone areas and also the use of biotechnical slope techniques and bioengineering methods. Application of these recommended methods/ practice will go a long way in reclaiming affected lands and solving the problems of failed slopes, expansion of the gullies and continuous landslide hazards in the study area.

Conclusions

The origin, mechanism and effects of landslides hazards have been investigated in Iguosa and its environs, Western Anambra Basin, Nigeria. Field observation reveals that the geomorphological characteristics, weakly developed structure, high slope instability, wrong use of land, as well as the steepness of the slope, contributed to the origin of landslide as well as the gully erosion in the study area. Intense and prolonged rainfall also contributed gully and landslide initiation and occurrences. The unconsolidated nature of the soil, less cohesion, high permeability, and weak plasticity of the soil that occurs under and above the clay lithologic units contributed to landslide and gully erosion. There is high water pore pressure that develops at the sand - shale boundary in the study area. When this excess water is released at boundaries between sand-clay layers it gives rise to swollen, shrinking and sliding in future because of the characteristics of slope materials. Over four hundred (400) houses, other properties and farmlands have been destroyed and abandoned in the study area. The following suggestions have been made to solve this problem by covering the landslide areas with impermeable layers/materials, diverting surface water away from the landslide areas, enacting laws to prevent erection of structures on landslide prone areas, good drainage system, the use of biotechnical slope techniques and bioengineering methods.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data materials

Data and materials generated and analysed are available in this research work.

Competing Interests

There was no competing interest among authors.

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Authors' contributions

Godwin Okumagbe Aigbadon: He led the team for the field investigation / mapping, collection of data, data analysis and drafting of the manuscript.

Azuka Ocheli: He supported in the field investigation, collection of data, data analysis and writing of the manuscript.

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Abbreviations

K�a: Kilopascal; K: Permeability; LL: Liquid limit; PL: Plastic Limit; PI: Plasticity index; NP: Non plastic; M: Meters; CM: Centimeter; µ: Mean; SB: Soil samples; Secs: seconds

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Table 4

Table 4: Geotechnical parameters for soil samples (SB) in the study area

Sample Number	Cohesion (k□a)	Angle of internal resistance (O)	Coefficient of permeability (m/sec)	Liquid limit (LL)	Plastic Limit(PL)	Plastic Index (PI)	Grain size
SBI	28	27	3.6×10^{-4}	34	4	30	Sandy clay
SB2	27	30	4.0×10^{-4}	38	2	36	Sandy clay
SB3	10	24	3.0×10^{-4}	25	NP	NP	Coarse grained sand
SB4	16	26	2.8×10^{-4}	26	NP	NP	Coarse grained sand
SB5	45	10	4.8×10^{-4}	76	36	40	Silty clay
SB6	27	28	3.5×10^{-4}	33	3	30	Sandy clay
SB7	27	30	4.2×10^{-4}	38	3	35	Sandy clay
SB8	12	24	3.2×10^{-4}	24	NP	NP	Coarse grained sand
SB9	18	25	2.8×10^{-4}	26	NP	NP	Coarse grained sand
SB10	46	12	4.6×10^{-4}	76	35	41	Silty clay
	μ=25.6	μ=23.70	μ=3.65×10^{-4}	μ=40.00	μ=8.30	μ=21.20	

Note: SB represent samples, μ= mean

Figures

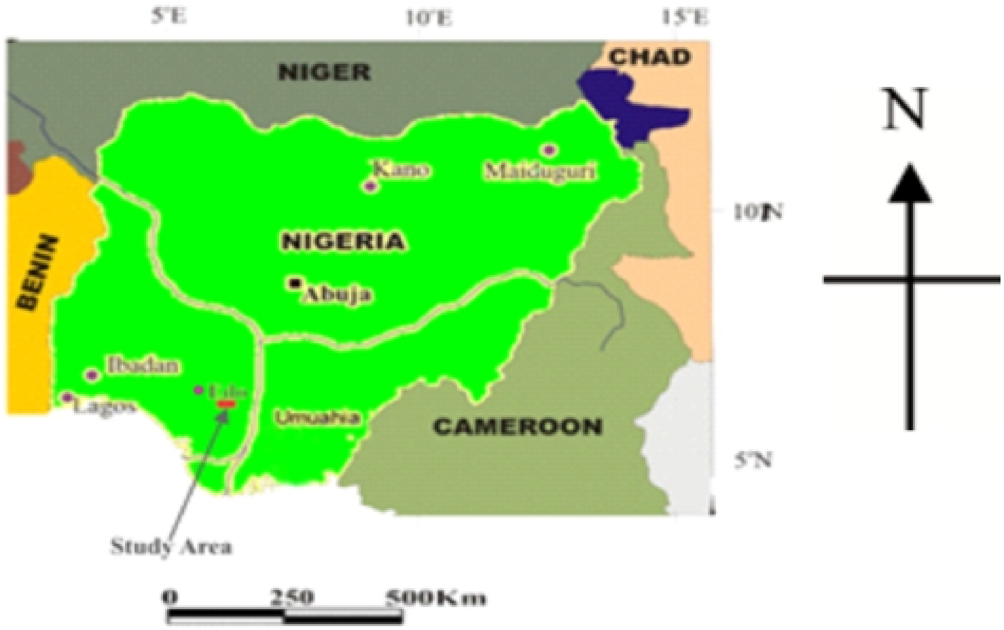

Figure 1

Map of Nigeria showing study area (Igwe and Una 2019). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

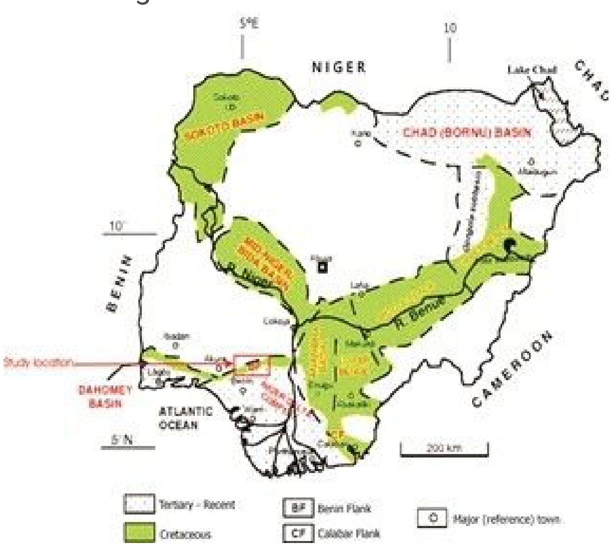

Figure 2

Map of Nigeria showing the Benin Flank, Western Anambra Basin in the field location (Obaje, 2011). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

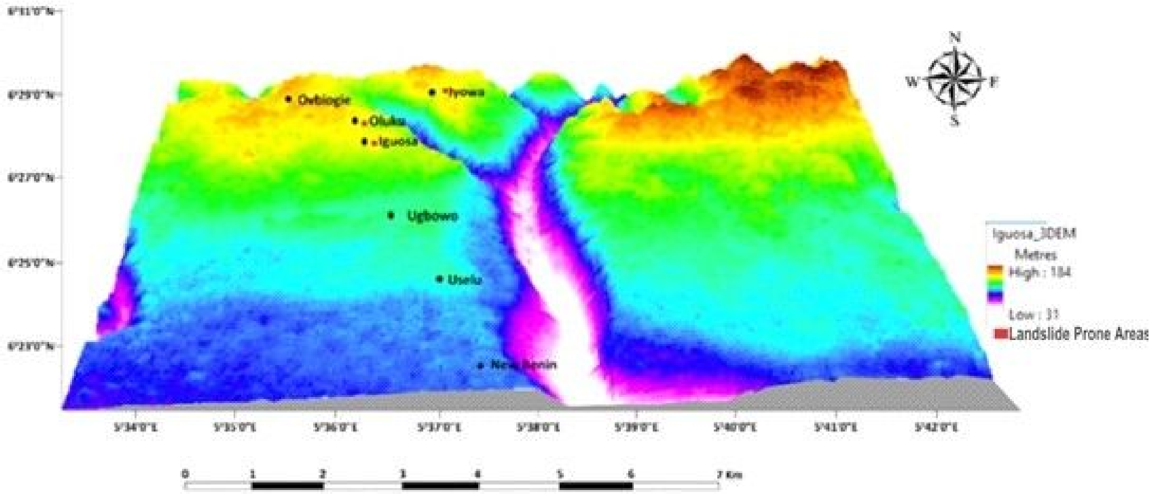

Figure 3

Digital elevation map of Iguosa and surrounding environs showing landslides prone areas.

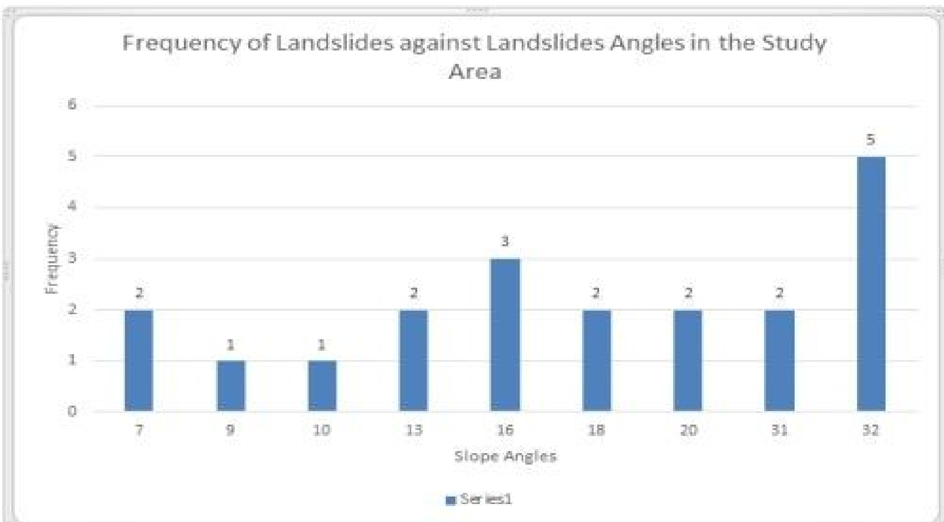

Figure 4

Graphical representation of frequency of slope angles of gullies/landslides in the study area

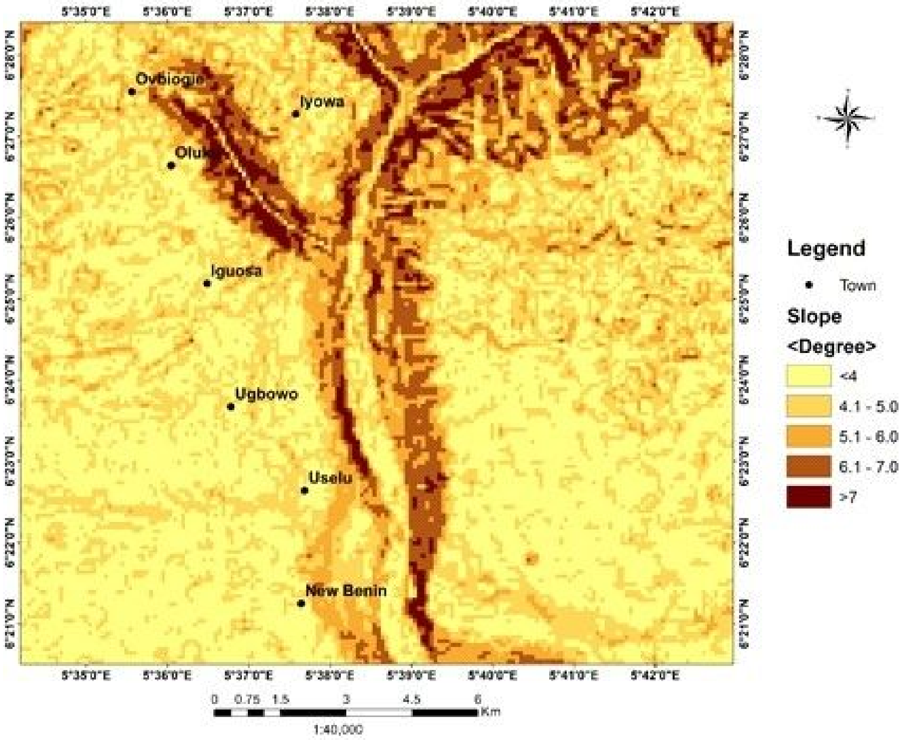

Figure 5

Slope angles of Iguosa and its surrounding environs

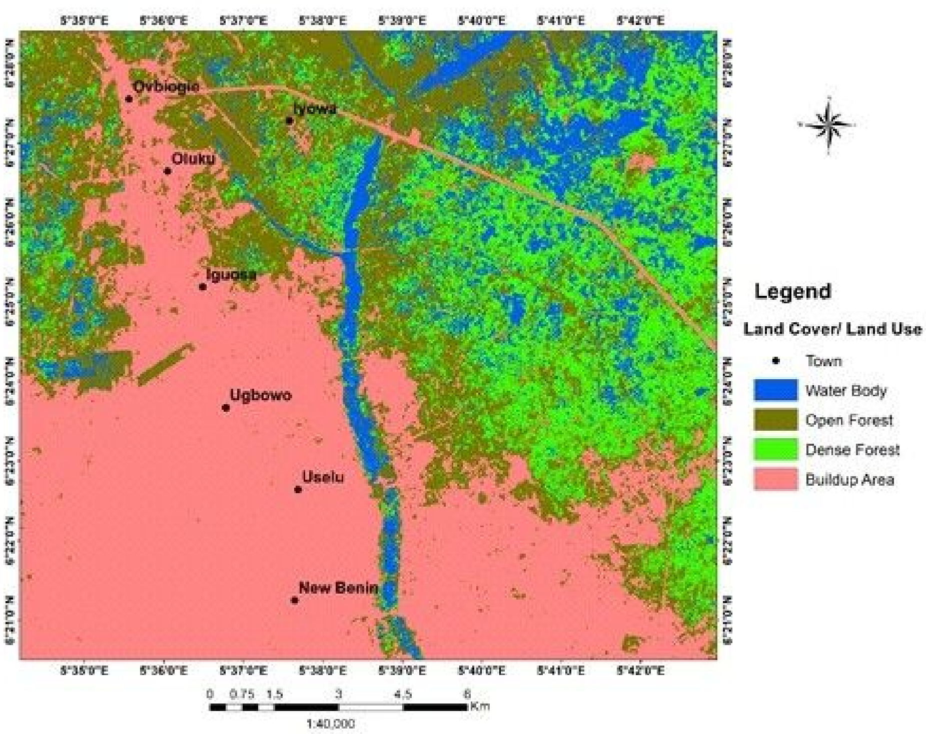

Figure 6

Land cover map of Iguosa and its environs. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

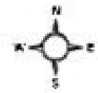

Figure 7

Plot of Dimensions of landslides (m) against slope angles of the landslide

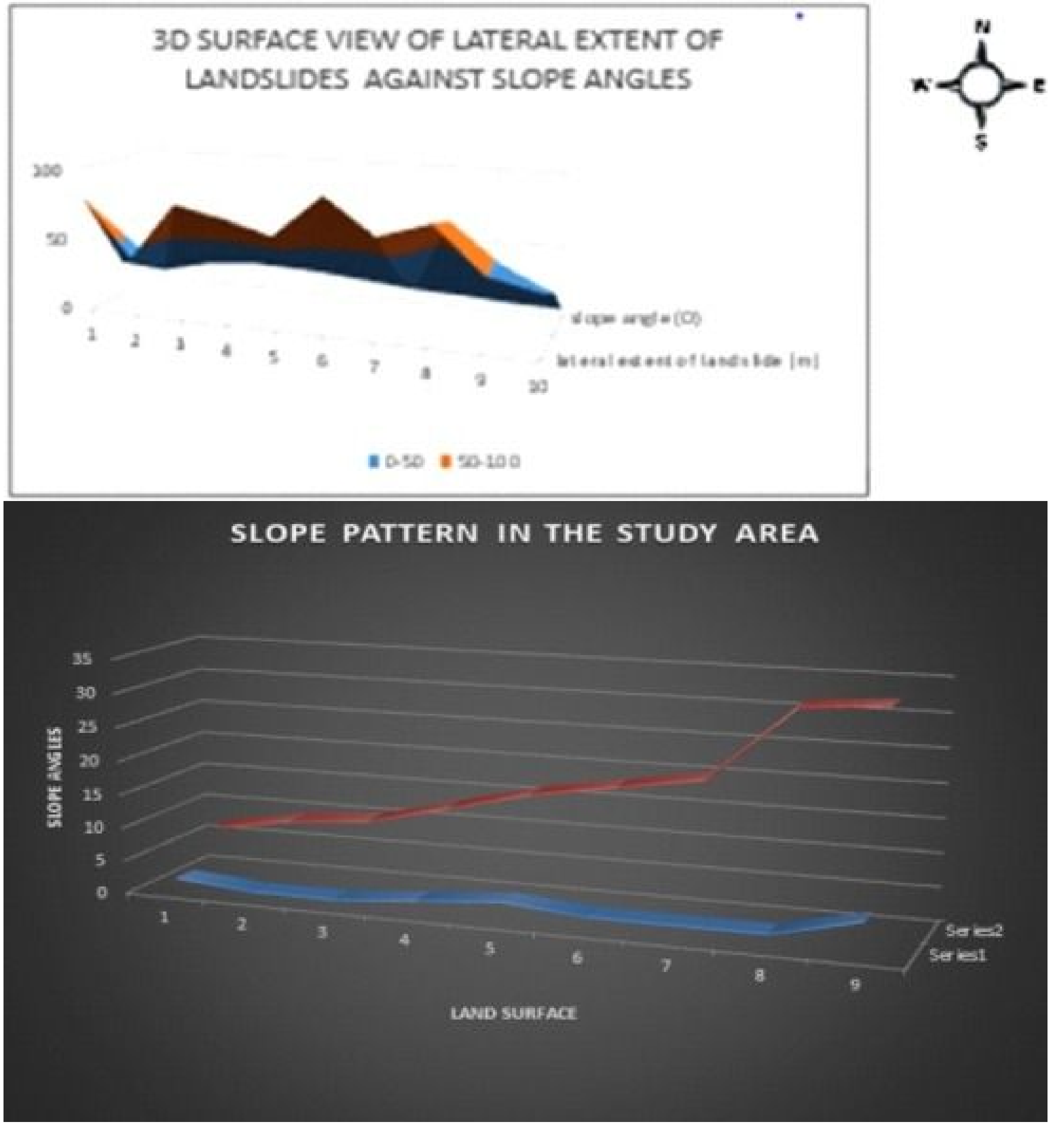

Figure 8

a: 3D surface view of lateral angles versus slope angles of the landslide in the study area. b: Slope pattern of the sliding in the affected areas

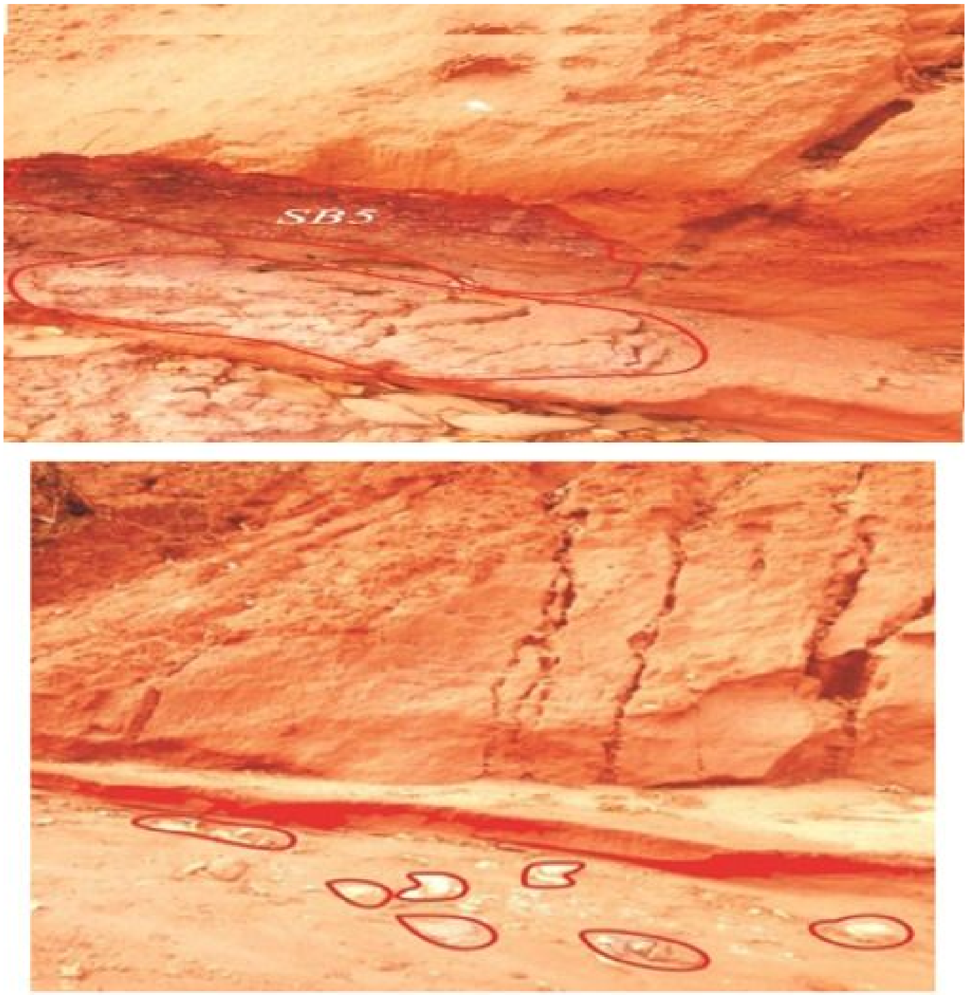

Figure 9

a: Shale/clay materials (SB5) acting as gliding surface in the study area (Photo by Aigbadon). b: Weathered Shale/clay materials on the floor in the study area which acts as sliding plane (Photo by Aigbadon)

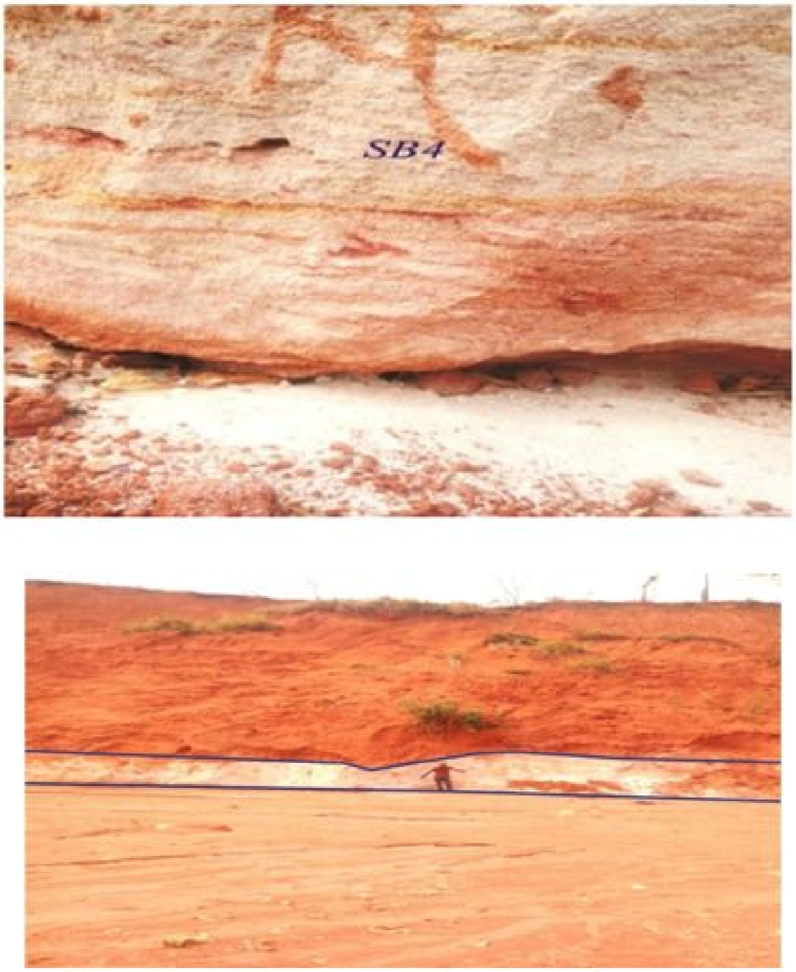

Figure 10

a: Ajali Sands (SB4) in the study area (Photo by Aigbadon). b: Ajali Sands with thickness of about 2.5m marked blue in the study area (Photo by Aigbadon)

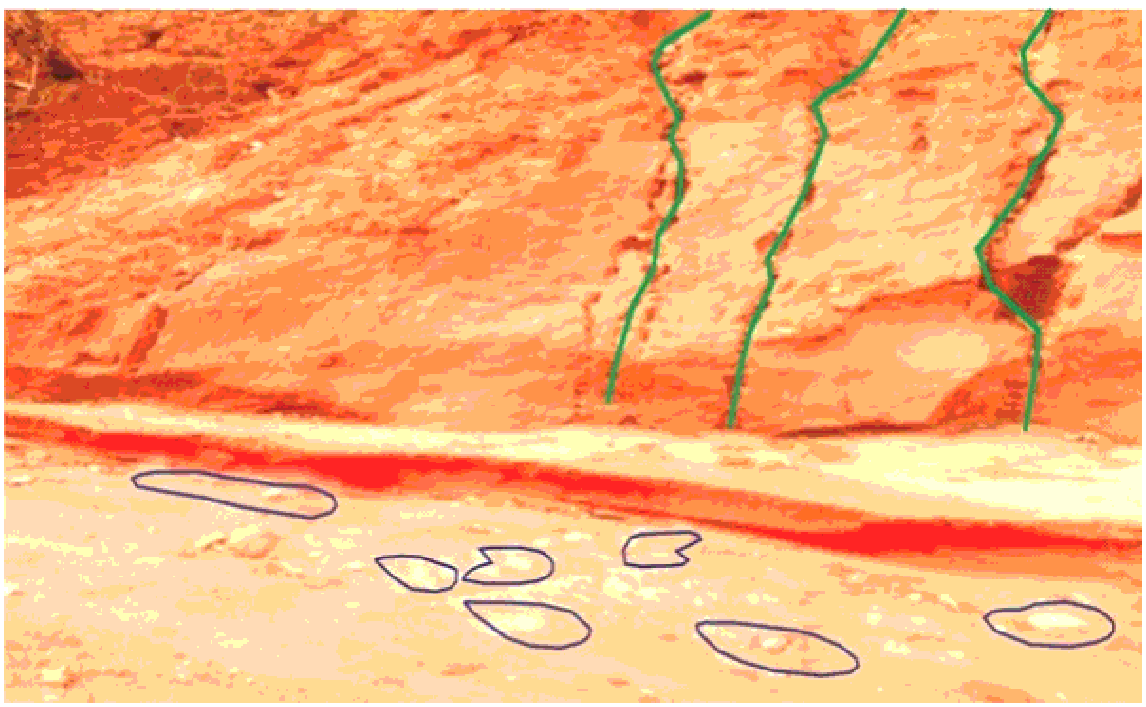

Figure 11

Cracks and fractures zones marked in green (Photo by Aigbadon)

Figure 12

a: Soil debris in the study area (Photo by Aigbadon). b: lateral soil spread in the study area (Photo by Aigbadon)

Figure 13

landslide at the study location (Photo by Aigbadon)

Figure 14

a: Landslide on Iguosa area threatening lives and Property in the study area (photo by Aigbadon). b: The road leading to various homes in the study area has be truncated by erosion and landslides activities (photo by Aigbadon)

Figure 15

Surface water diverted to the landslides area couple with the poor drainage system (photo by Aigbadon)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix1.docx