Aigbadon *et al. Environ Syst Res* (2021) 10:36
https://doi.org/10.1186/s40068-021-00240-6

Environmental Systems Research

RESEARCH Open Access

Geotechnical evaluation of gully erosion and landslides materials and their impact in Iguosa and its environs, southern Nigeria

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Abstract

Background: Detailed field surveys and geotechnical evaluation of soils in Iguosa and its environs, Southern Nigeria, were undertaken to determine the root causes, mechanisms, and impacts of landslides and gully erosion. This was done to suggest appropriate mitigation measures to reclaim the affected land and prevent future occurrences in the study area.

Results: Field study revealed high elevations, a steep slope, high rainfall and inadequate drainage systems. Also, human activities and socio-cultural activities have contributed to the large lateral extents in depths and widths of the landslides and gullies in the study area. The geotechnical analyses reveal that soil samples from SB1, SB2, SB6 and SB7 lithological units are mainly sandy clay with a coefficient of permeability ranging from 3.5×10^{-4} to 4.2×10^{-4} cm/s, the cohesion ranges from 27 to 28 kpa and angle of internal resistance ranges from 27° to 30° respectively. The plastic limit ranges from 2 to 4, and liquid limit ranges from 33 to 38, and the plasticity index ranges from 30 to 36. Ajali sand units SB3, SB4, SB8 and SB9, consist of coarse-grained sand with no plasticity. The coefficient of permeability ranges from 2.8×10^{-4} to 3.2×10^{-4} cm/s, the cohesion range from 10 to 18 kpa, angle of internal resistance 24° to 26°, respectively. The soil samples from SB5 and SB10 lithological units are silty-clay with a coefficient of permeability of 4.6×10^{-4} to 4.8×10^{-4} cm/s. The cohesion of 45 to 46 kpa, and angle of internal resistance of 37° to 40°, respectively. The plastic limits ranges from 35 to 36, and liquid limit is 76, and the plasticity index ranges from 40 to 41.

Conclusion: Field survey and geotechnical evaluations of the soils revealed that high elevation, a steep slope and the geotechnical properties of the soils were the initial conditions that initiated landslides and gully developments in the study area. This has also *been* influenced by rainfall, poor vegetation, inadequate drainage systems, and human activities as well as socio-cultural activities. Over four hundred and thirty-two houses and farmlands and other properties have been damaged and abandoned in the study area. Covering the landslide areas with impermeable layers/materials, diverting surface water away from the landslide areas, enacting laws to prevent the erection of structures on landslide prone-areas, sound drainage systems, the use of biotechnical slope and bioengineering methods, afforestation and re-vegetation were the proposed mitigation measures to tackle this menace in the study area.

Keywords: Geotechnical survey, Landslides, Plasticity, Cohesion, Permeability, Slope, Sandy-clay

Background

Landslide is one of the major landscape disasters that has damaged buildings and other physical properties worth millions to billions of dollars annually during the rainy seasons (Igwe 2015). Cruden and Varnes (1996), Iverson (2000), Jakob et al. (2006), Yalcin (2007), Igwe and Fukuoka (2010), Msilimba and Holmes (2010), Wang

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et al. (2002), Sassa et al. (2004), Guzzetti et al. (1999), Igwe (2015), Igwe and Una (2019) conducted study on mechanisms associated with rainfall-induced landslides and these have been well documented. They are of the opinion that Intense and prolonged rainfalls, degree of slopes, discontinuities, weathering, and flooding are the major factors predisposing landslides globally. Brand et al. (1984) believed that most landslides and erosional activities in Hong Kong were rainfall-induced either as concentrated or short-duration rainfall of high intensity. Koko and Chowdhury (2005) had similar observations that the landslides and gully erosion and the associated risk correlated with rainfall-induced landslide along the railway of high slope angles ranging from 32° to 42°. Sikdar et al. (2004) worked on the Raniganj coal mining area of Western Bengal and found out that the degree of slope within the study area varies from 0° to 15°. It shows that the slope of the area ranges from very gentle to moderate slope. Chen et al. (2012a, b) attributed the 2008 Wenchuan earthquake to have occurred on areas with slope angles varying from 30° to 50°. The heavy rainfall mechanism associated with long run-out triggered the 'August 1998' landslides in Fukushima Prefecture, Japan. The affected inhabitants of these affected areas were relocated to a more stable environment. In West African countries, landslides are caused primarily by rainfall (Igwe 2015). In recent times, Nigeria has witnessed a high frequency and variation of landslides and erosional activities caused by geological settings. Ayodele et al. (2020) conducted geological assessment of landslide occurrences in the Okemesi area in southwestern Nigeria to determine the geotechnical properties of the soils. They concluded that the rocks in Okemesi were intensely fractured and thus contributed to the occurrence of landslides in Okemesi. The prolonged rainfall of October 2013 initiated twenty-eight (28) new shallow landslides and gully erosion in the Enugu and Obudu area around Calabar, which resulted in several casualties and severe economic loss (Igwe 2015). Ogbukagu (1976), Varnes (1978), Egboka and Okpoko (1984), Okagbue (1986, 1992), Igwe et al. (2013), Igwe (2015), Egboka et al. (2019), Ocheli et al. (2021) carried out detailed studies on landslides and gully erosion in Nanka and other parts of Anambra Basin, Southeastern Nigeria, using field campaigns and geotechnical techniques in many learned journals. Ocheli et al. (2021) carried out detailed studies on geology and geotechnical investigations of Anambra Basin, Southern Nigeria using field and various laboratory techniques. They found that gully erosions have been developing on steep slopes and non-vegetated areas. The genesis of the gullies was accelerated by the cohesionless and very permeable nature of the sand formations. The impacts and mitigation measures of landslides in the Nanka area of Anambra Basin were carried out using field monitoring, laboratory analyses and limit equilibrium simulations. The study also shows that the topography of the Nanka areas have been negatively affected by landslides and gully erosion. They revealed that the landslides and gully erosion was caused by factors like; water infiltration, high slope gradient, and poorly consolidated and non plastic sands. These sands were overlain by the less permeable silt–clay units. The ground is continuously saturated with water whenever there is torrential rainfall. Torrential rainfall often led to the build up of water pressure within a perched aquifer, which reduces the shear strength and cohesion of the soil and ultimately initiates landslides and gully erosion (Fukuoka 1980; Wieczorek 1996; Li et al. 2005; Lee et al. 2012; Igwe et al. 2013). Despite the fact that various mitigation measures recommended and adopted by many scholars, including the provision of sufficient drainage systems in an area of slope failures (Highland and Bobrowsky 2008), biotechnical slope techniques, and soil bioengineering method (Gray and Leiser 1982; Gray and Sotir 1996) and the use of bamboo trees as demonstrated in some parts of Oko and Amucha in Southeastern Nigeria (Igwe and Una 2019), the incidence of landslides and gully erosion have continued to occur and reoccur in different parts of Nigeria. Omon and Ogheruemusua (2014) have evaluated soil erosion in the Benin metropolis, Edo State, and found out that rain is the main cause of soil erosion followed by soil character, and thus recommended construction of side drains and tunnels. The outcomes of these recommended measures employed in the study area remain unsuccessful, as landslides and gully erosions have continued to occur and reoccur at a very high magnitude, with over four hundred and thirty-two houses and farmlands damaged and abandoned. Detailed information about the root causes, mechanisms, and the continuous landslides and gully erosion in the study area is relatively lacking. The objective of this study is to identify the root causes, mechanisms and impact of landslides in the study area. In addition, regarding landslides and gullies studies in the study area, there is no existing research work of such magnitude has been done. Effective mitigation measures shall be suggested to reclaim the affected land and avoid future occurrences and reoccurrences of these disasters in the study area.

Location and climatic conditions

The study area in Southern Nigeria, is between latitudes 6° 20^{1}N and 6° 50^{1}N and longitudes 5° 40^{1}E and 5° 00^{1}E, respectively (Fig. 1). The study area has two distinct seasons; the rainy and the dry seasons. The rainy season begins in April and stops in October, while the dry season begins in November and ends around March. The study area has a total annual rainfall range of 1600–2220 mm

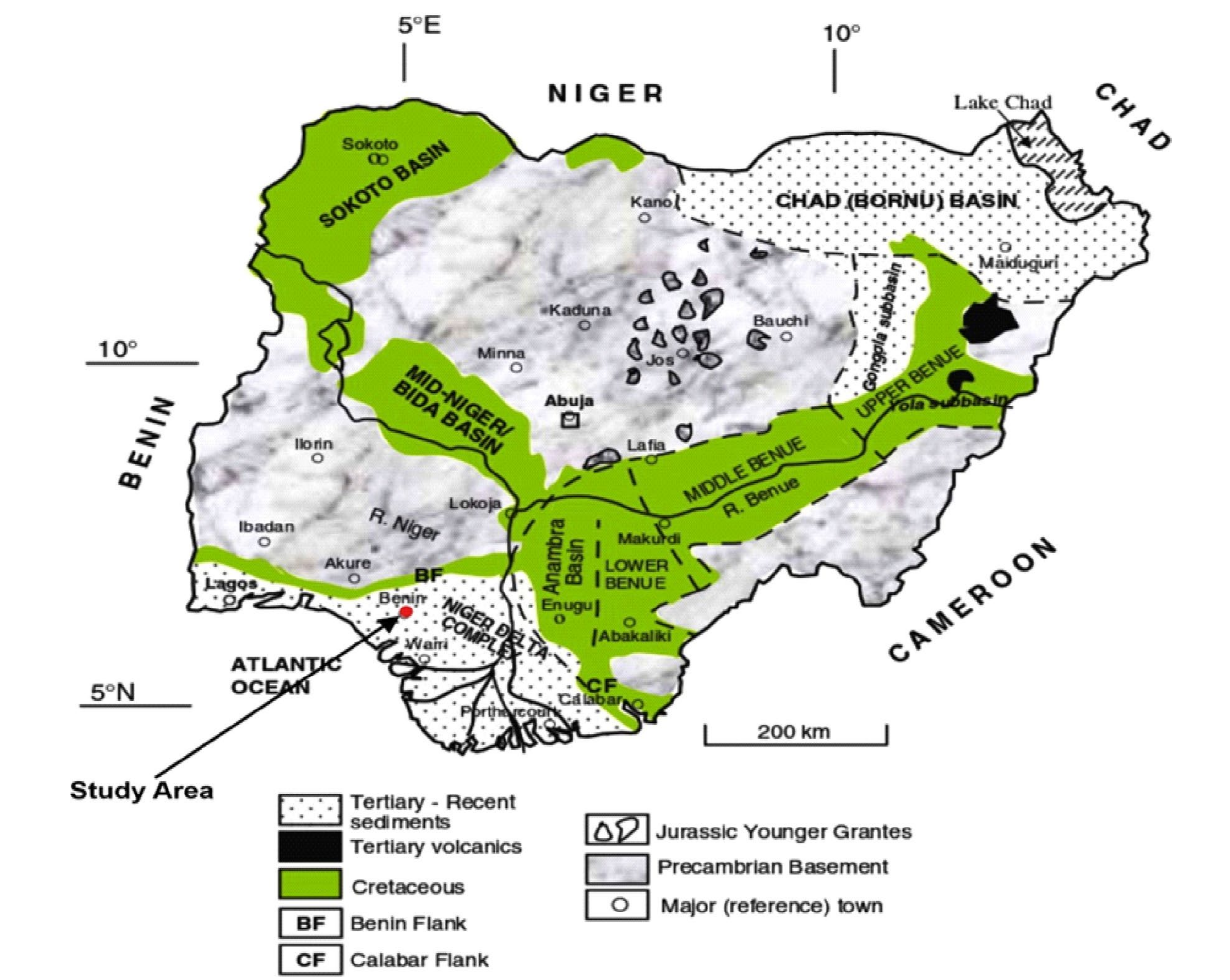

Fig.1 Map of Nigeria showing the study area (Obaje et al. 2004)

(Nimet 2010; Ukhurebor and Abiodun 2018). The mean monthly temperature during the rainy season ranges from 20 to 28 °C (Nimet 2010), and the mean monthly temperature during the dry season ranges from 28 to 33 °C (Nimet 2010; Ukhurebor and Abiodun 2018), respectively. The areas of study are within the tropical rainforest belt and are mainly of trees and shrubs.

Geology of the study area

The geology of the study area comprises quaternary deposits, Benin Formation, Ajali sands, and Ogwashi-Asaba Formation. Kogbe (1976) classified Ogwashi–Asaba Formation as gritty sands, clay, and lignite seam with clay intercalations of continental depositional setting. Reyment (1965), Kogbe (1976) gave the age as Miocene to Recent. Akujieze (2004) stated that it is exposed at the stream channels of the Northern part of the Benin area towards the west of Ekiadolor—Iwu, Utekon and North Azalla.

The Benin Formation comprises of top reddish to brown lateritic soil, clay, very coarse to coarse, very poorly to poorly sorted sands, and sometimes ferruginous sandstone, gravels, and netlike mud cracks. The thickness ranges from 800 m thick around Benin City to 1830 m towards the sea (Ikhile 2015). The environment of deposition is mainly continental (Short and Stauble 1967; Evamy et al. 1978; Weber and Daukoru 1978). The red earth sand is coastal plain environments that 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 primarily reddish to brownish-white sands, silts, clayey sands, and gravels.

Materials and methodology

The primary information used in this study includes field campaigns, photographs of landslides and gullies, field measurements, generated maps, and interpretations from the result of geotechnical soil indices. Thematic maps of 3-D topographic elevation model slope and land use was produced using remote sensing data with the aid of Arc GIS 10.50 software to ascertain areas vulnerable to landslides and gullies in the study area. The 3D topographic elevation, slope and land use map was produced using Shuttle Radar Topographic Mission (SRTM− 30 m data) and Enhanced Topographic Mapper Plus (ETM+) data collected from the USGS website.

The landslides in the study area were described and classified according to (Cruden and Varnes 1996; Perucca et al. 2009). In the study area the magnitude/degree of the landslides was evaluated from the crown to the toe of the rapture. The exact location of gullies and landslides in the field was determined with the Global Positioning System (GPS). Ten samples were collected at sidewalls, slide floors of the landslides and gullies, respectively and well-labeled at the point of collection. The GPS readings were taken at this point of samples collections at landslides and gully locations. Each soil was collected by driving the hand auger to a plough depth of 15 cm to draw the soil samples. These samples were collected from the topsoil (15 cm) by removing the topsoil, slide walls and the slide floors, respectively. Each collected samples were labelled correctly, wrapped carefully with newspapers and placed in each polythene bags before taking them to the laboratory for further analysis.

The depths, length, width, lateral extent of the slides were measured using measuring tapes. The slope angles and the elevations of the gullies and slides in the study areas were measured with a clinometer and Global Positioning System (GPS) respectively. The limitations of study were the presences of thick vegetation, steep and deep gullies and rugged terrains that made the accessibility and sample collections challenging.

Geotechnical analyses

A set of British Standard sieve of various diameters 4.875 mm, 3.55 mm, 2.36 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 150 µm, 75 µm with a receiver pan were used to carry out the sieve analysis to determine the percentage retained on each sieves using the procedures described by the British standard (1990) methods as also explained by other authors (Ishaque et al. 2010; Ocheli et al. 2021). 50 g of each soil samples were washed and oven-dried and after that passed through the set of sieves. The atterberg limits comprising liquid limit tests and the plastic limit tests was carried out according to (British Standard 1990; Ishaque et al. 2010). The liquid limit test were performed using Casagrande grooving device to groove 50 g of each soil samples, and the plastic limit of each 50 g soil samples was roll out in a thread of the 50 g of soil samples on a flat, non-porous surface with the aim of evaluating the behavioural characteristics of the soils (Ocheli et al. 2021). The plastic limit test was performed under the methodology described by the British Standard Method for Testing Soils (B.S. 1990). Sohne (1953), Ocheli et al. (2021) determine the shear strength of the soils using a vane shear apparatus as described. The significance is to determine the values for cohesion and angle of internal resistance between the grains, respectively. Munch and Douglas (1985), BS 1377.5 (1990) determine the permeability of the soil using the constant head permeability test.

Results and discussion

Results of the field study

From Table 1, the result of the elevation of the study area ranges from 22.86 to 332.0 m, with a mean elevation of 183.11 m. Lateral extent ranges from 40.2 to 93.0 m with a mean value of 87.3 m. The depth ranges from 2.6 to 68.7 m with a mean value of 57.07 m . The width ranges from 20.4 to 72.6 m with a mean value of 32.24 m. The slope steepness (angle of a slope) range from 7° to 32° with a mean value of 20.25°. Slope values as classified (Sikdar et al. 2004; Ocheli et al. 2021), indicates that values of < 0.5° indicates very gentle slope, 5 < 10° indicates gentle slope, 10 < 15° indicates moderate slope, 15 < 25° indicates moderately steep slope, 25 < 35° indicates steep slope and, > 35.0° indicates a very steep slope. Based on the results obtained in (Table 1), which ranges from 7° to 32°, compared with the class and description of slopes (Sikdar et al. 2004; Ocheli et al. 2021), the degree of steepness of the study area falls within an interval of gentle to a steep slope. The frequency of the slopes is shown in Table 2. The generated digital elevation model, slope map, and land use map of the study area from 30 m data—Spatial Resolution and Shuttle Radar Topographic Mission (SRTM) are captured (Figs. 2, 3, 4). It shows that the elevation, the steepness of the slope, and poor land contributed to the landslides and gullies in the study area. Other factors which contributed to continuous land sliding and gullies in the area are run-off from heavy downpour and infiltration, deforestation, overgrazing, and flawed drainage system. During the early stage of land-sliding and gullying activities, the lateral extent and width of the slides were not initially proportionate. As the landslides and gullies become rapid, the lateral extent of the sliding becomes relatively proportional to

Table 1 Field measurements for gullies and slides in the study area

S/N	Longitudes (E)	Latitudes (N)	Elevations (m)	Lateralextents (m)	Depth (m)	Width (m)	Slopeangle (°)	Description of slope
1	05°41′23″	06°27′40″	332.00	80.0	68.7	23.2	32	Steepslope
2	05°37′43″	06°29′41″	310.80	40.2	68.2	20.4	31	Steepslope
3	05°43′16″	06°28′32″	306.00	80.0	66.9	28.4	20	Moderately steepslope
4	$05^{0}40'10''$	06°28′30″	200.40	73.0	66.3	31.6	18	Moderately steepslope
5	05°12′13″	06°24′00″	120.00	64.0	64.7	30.4	16	Moderately steepslope
6	05°13′13″	06°04′14″	118.60	93.0	67.0	33.8	13	Moderateslope
7	05°32′07″	06°32′00″	58.40	69.4	67.1	33.7	10	Moderateslope
8	05°12′18″	06°37′01″	26.30	80.2	20.3	72.6	09	Gentleslope
9	05°37′13″	06°25′00″	24.70	50.2	4.1	46.7	07	Gentleslope
10	05° 35′00″	06°27′01″	22.86	43.0	2.6	30.4	07	Gentleslope
11	05°32′13″	06°24′00″	120.00	64.0	60.7	40.4	16	Moderately steepslope
12	05°34′00″	06° 27′01″	118.60	93.0	65.0	34.8	13	Moderately steepslope
13	05°37′13″	06°28′32″	306.00	80.0	66.9	28.4	20	Moderately steepslope
14	05°41′30″	06°27′40″	200.40	73.0	64.3	32.6	18	Moderatelysteepslope
15	05°52′13″	$07^{0}34'00''$	120.00	64.0	64.7	32.4	16	Moderately steepslope
16	05°37′40″	06°26′30″	332.0	80.0	60.7	24.2	32	Steepslope
17	05°38 13″	06°25′00″	310.80	40.2	68.4	20.4	31	Steepslope
18	05°43′16″	06°38′32″	308.00	80.0	66.9	30.4	32	Steepslope
19	05°44′10″	$06^{0}38'30''$	204.40	73.0	64.3	32.6	32	Steepslope
20	05°45′13″	06°40′00″	122.00	64.0	63.7	30.4	32	Steepslope
			MEAN = 183.11	MEAN = 87.30	MEAN = 57.07	MEAN = 32.24	MEAN = 20.25	Remarks: gentle steep-slopes

Table 2 Frequency of slope angles of the slides and gullies in study area (2020–2021)

Slopes angles of the landslides (°)	Frequency of the landslides
7°	2
9°	1
10°	1
13°	2
16°	3
18°	2
20°	2
31°	2
32°	5

the slope angles of the landslides (Fig. 5a). From Fig. 5b, the blue colour shows the initial stage of the sliding as a very gentle to gentle slope. The red colour shows the advanced stage of sliding from a moderately steep slope to a steep slope in the study area. As the width of landslides increases, the lateral extent of the landslides relatively increases, and these occur more on the slope angles of 22.5° and elevations of 183.11 m. From the plot of the dimensions of the landslide against the slope angles of the landslides (Fig. 5a). The elevation, width, and depth values of the landslides and gullies indicate that the sliding is almost at the same rate. These sliding activities are prominently trending in the northeast direction of the study area (Fig. 5b, c). The lithological study revealed that the topmost layer of the gully profile consists of dense lateritic soil, underlain by Ajali sands and then some clay materials at the slide walls and floor of the slides/gullies. The Ajali sand is primarily medium to coarse-grained, friable, and unconsolidated sands of 250 cm thickness in the landslides area. Also, within the landslide areas, the units are inter-bedded by clay and silty soils. The photographs of some of the landslides and gullies in the study area are displayed (Fig. 6a–e).

Result of geotechnical analyses

The result of the soil samples (Table 3) collected from the landslides and gully prone areas shows that soil samples SB1, SB2, SB6, and SB7 are mainly sandy clay with a coefficient of permeability ranging from 3.5×10^{-4} to 4.2×10^{-4}cm/s, cohesion ranging from 27 to 28 kpa and angle of internal resistance ranging from 27° to 30° respectively. Surenda and Sajeev (2017) classified angles of internal resistance between grains as: < 28° shows very loose compaction, ≥ 28°–30° displays loose

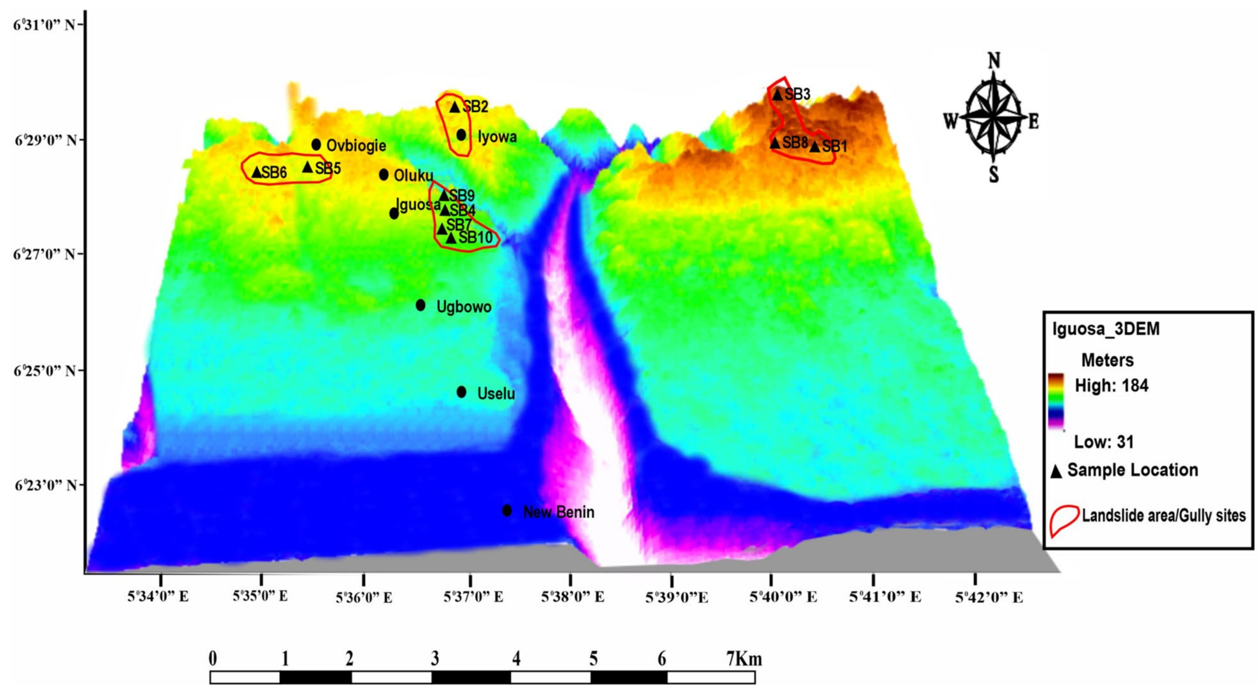

Fig. 2 Digital elevation map of Iguosa and surrounding environs showing landslides prone areas generated from NASA SRTM-30 m

compaction, ≥ 30°–36° indicates medium compaction, ≥ 36°–41° indicate dense compaction, ≥ 41° shows very dense compaction. From Surenda and Sajeev (2017), it shows that soil samples from these lithological units range from very loose compaction to loose compaction. The plastic limit ranges from 2 to 4, and liquid limit ranges from 33 to 38, and the plasticity index ranges from 30 to 36. According to Sowers and Sowers (1970), PI > 31 is high. Soil samples SB3, SB4, SB8, and SB9 from Ajali sands are coarse-grained sand that is not plastic, has a coefficient of permeability ranging from 2.8×10^{-4} to 3.2×10^{-4}cm/s, cohesion 10 to 18 kpa. The angles of internal resistance range from 24° to 26°, indicating very loose compaction. Soil samples SB5 and SB10 lithological units are silty-clay with a coefficient of permeability of 4.6×10^{-4} to 4.8×10^{-4}cm/s, the cohesion of 45 to 46 kpa, and angle of internal resistance of 37° to 40° indicating dense compaction. The plastic limits for SB5 and SB10 ranges from 35 to 36, liquid limit 76, and a plasticity index range of 40 to 41. From the soil analysis, plasticity index of 40 in the study area depicts high plasticity. SB5 and SB10 have a very high liquid limit value of 76, and this conforms to Bell (2007) classification of clays in terms of liquid limits which states that values ranging from 70 to 90 are very high plasticity.

Discussion

Causes and negative impacts of landslides and gully erosions in the study area

Field and geotechnical evaluations of the soils of the study area revealed that the high elevation and a steep slope and the geotechnical properties of the soils are the initial conditions that initiated landslides and gully developments in the study area; hence, the large lateral extents, widths, and depths of the gullies. A very loose to lose compaction of the soils increases its susceptibility to erosion and landslides. The study area was influenced by high rainfall, surface water diversion, and human activities as well as socio-cultural activities. The slopes of gullies and landslides are covered with green vegetation during the rainy season. During the dry season the slopes of gullies and landslides are almost entirely bare due to overgrazing and drought during this season. Intense rainfall/excess run-off and soil erosion during the rainy season in the study area weakens the slopes by detaching the lateral base of the soil, thereby resulting in further steepening of the slopes. The digital elevation model, slope map, the land cover map generated from NASA SRTM 30 m data shows exactly the impact of elevation, slope, and vegetative/land cover on the principal cause, and continuous expansion of the gullies and landslides in the study area. The high permeability, low cohesion, low shear strength, frictional angles between grains, and non-plasticity of the Ajali sands are the factors responsible for initiating of slope failures, cracks, fractures, and

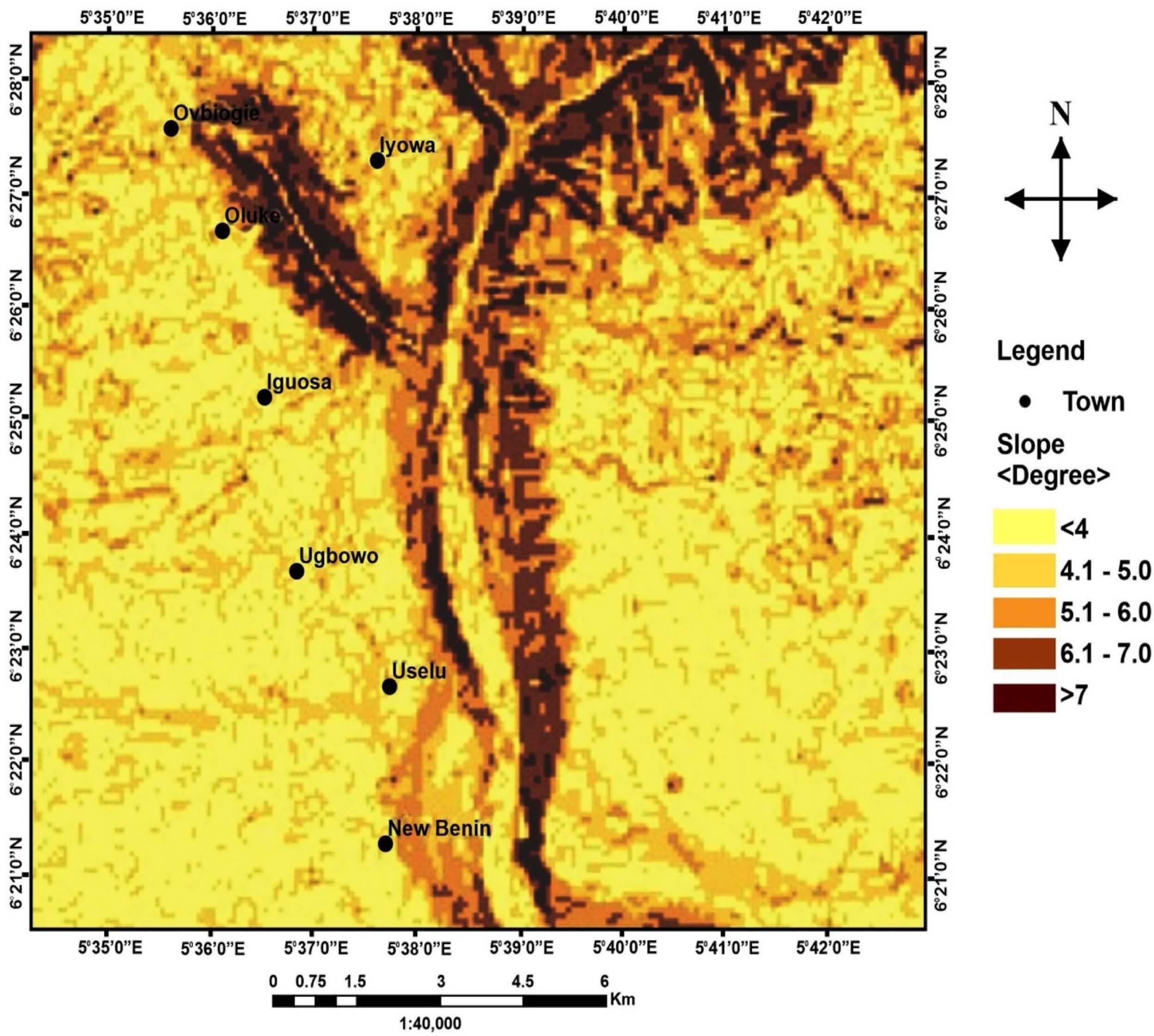

Fig. 3 Slope map of Iguosa and its environs

slopes of various degrees in the study area. The high permeability values show that the Ajali sands units SB3, SB4, SB8, and SB9 in the study area transmit enough volume of water into the underlying high plasticity and low permeability SB5 and SB10 (silt/clay) layers during heavy rainfall, run-off, and infiltration processes. A high pore-water pressure is developed within the Ajali sand-clay boundary. This will lead to the expansion of the clay layers (Fig. 7a), and an upward force is created on the overlying coarse sand to medium sand units as well as swollen, shrinking, and sliding activities. This alternating sequences of swelling and shrinking of the clay layer during wet and dry seasons also contributed to the initiation of the multiple slope failures, debris soil slide (Fig. 6c), and gully development in the study area. It also results in the development of new steep slopes at the base of the Ajali sands and other landslide activities in the study area. In addition to the very low permeability of silt/ clay units (SB5, SB10) that separates the sand units in the study area, the silt/ clay units (SB5, SB10) function as the gliding planes (Fig. 8a, b) that are responsible for several landslides in the study area. Inadequate drainage systems in the study area (Fig. 7b) cannot withstand the excess run-off during the rainy seasons. The excess water flow is trapped in narrow concentrated streams, which later create wide erosive channels in the earth's surfaces, thereby creating gullies of various forms, scales, and different sizes. Over four hundred and thirty-two houses, farmlands, and other physical properties have been damaged and abandoned in

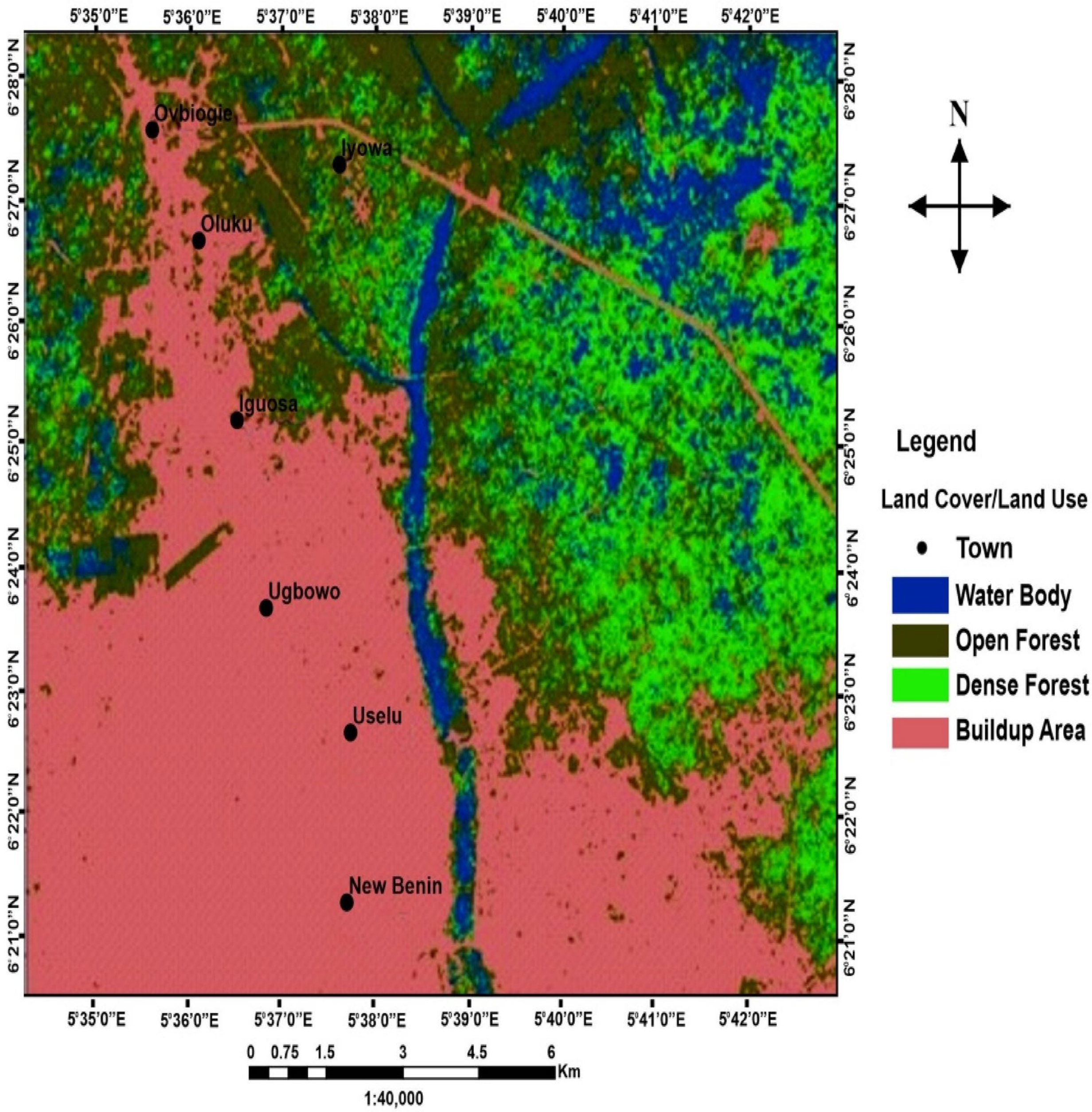

Fig. 4 Land cover map of Iguosa and its environs

the study area (Fig. 9a). The road leading to various homes and farmlands has been negatively affected by landslides and gully erosions in the study area (Fig. 9b).

The mechanism of landslides and gullies in the study area revealed that high intensity of the torrential rains during the peak of the rainy seasons (May–September), is a major contributing factor to initiating of gullies and landslides activities. In the study area, the Ajali sand is bounded at the top by lateritic soil and below by thin layers of clay/silt soil. The high permeability values of these soils show that the Ajali sand units in the study area transmit enough volume of water to the underlying (silt/clay layers) during the period of raining season. Within this sand-clay boundary, a high pore-water pressure is developed. This excess water from rainfall will be released between the Ajali sand and clay units causing swelling of clay. The increase in the volume of water will create an upward force on the overlying

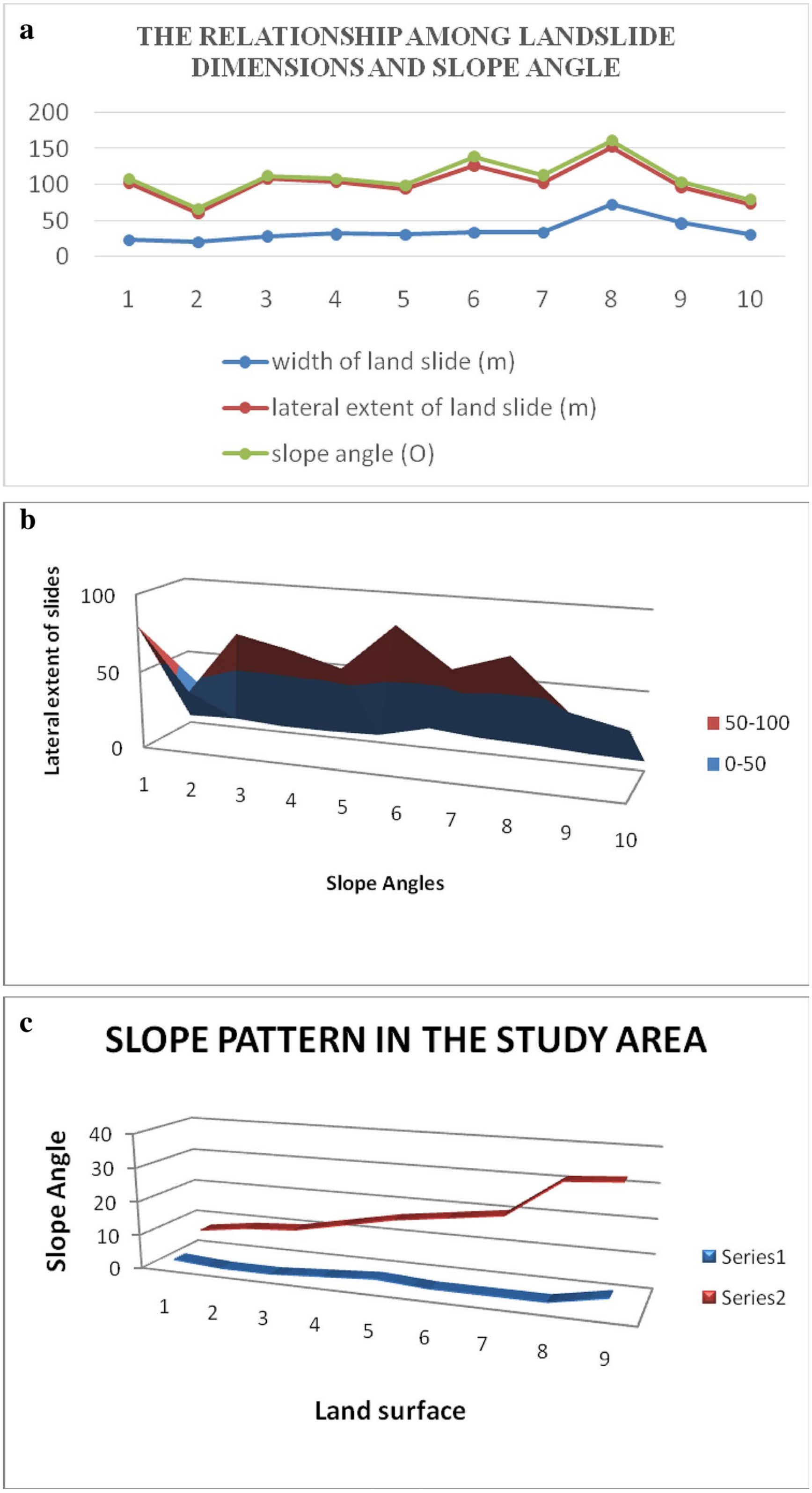

Fig. 5 **a** Plot of dimensions of landslides (m) against slope angles of the landslide. **b** 3D surface view of lateral angles versus slope angles of the landslide in the study area. **c** Slope pattern of the sliding in the study area

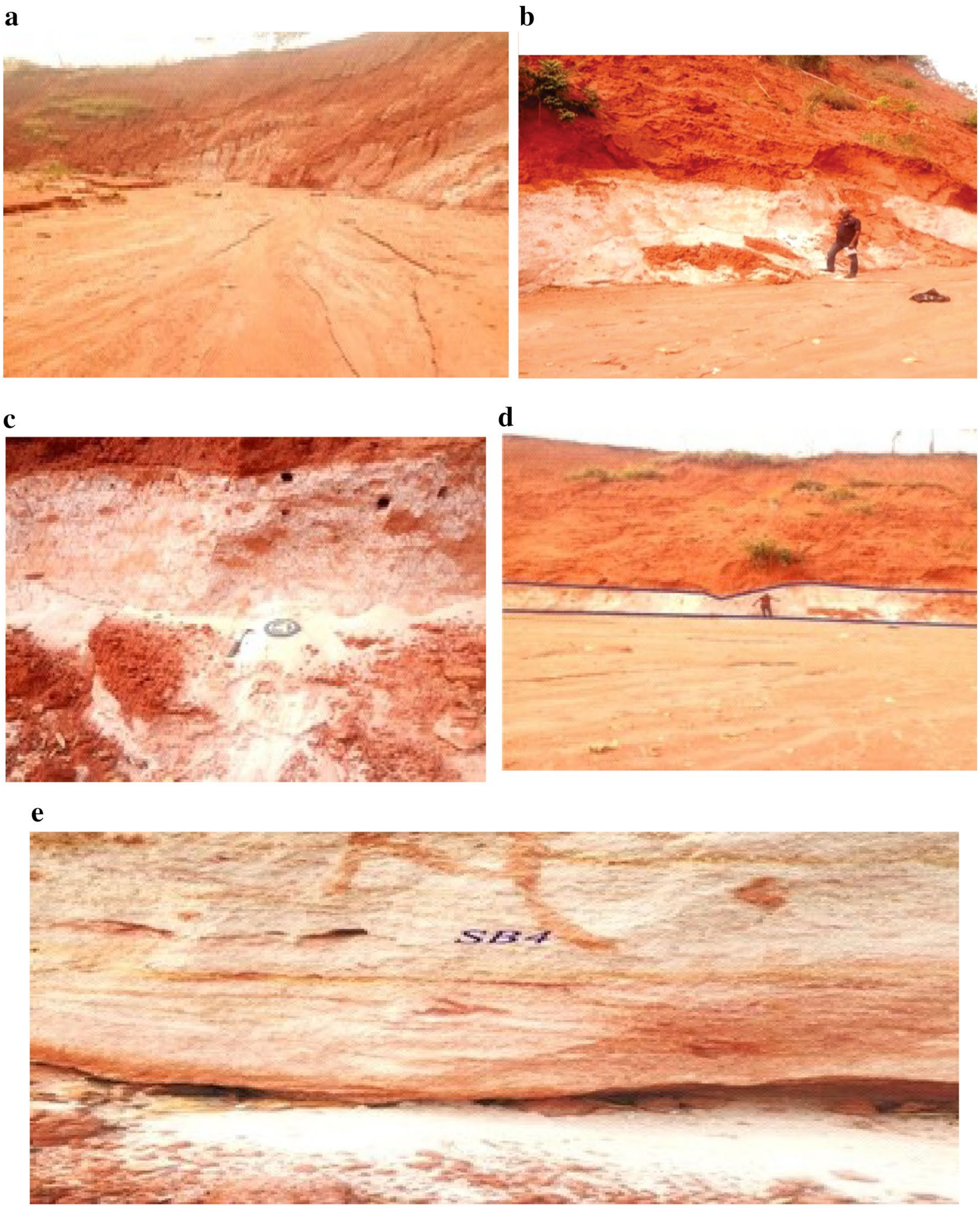

Fig. 6 **a** Landslide at the study location (photo by Aigbadon). **b** Lateral soil spread in the study area (photo by Aigbadon). **c** Soil debris in the study area (photo by Aigbadon). **d** Ajali Sands with thickness of about 2.5 m marked blue in the study area (photo by Aigbadon). **e** Ajali sands (SB4) in the study area (photo by Aigbadon)

coarse Ajali sand with very low plasticity. As a result of seasonal changes (wet and dry), the clay material experiences swelling and shrinking. This continuous alternation of swelling and shrinking of the clay layer beneath the Ajali sand initiates cracks, fractures which pave the way for weathering of the Ajali sands and clay

Table 3 Results of the geotechnical indices for the soil samples in the study area

S/n	Longitudes	Latitudes	Samples (SB) location	Cohesion (kpa)	Angle of internal resistance (°)	Coefficient of permeability (m/s)	Liquid limit (LL)	Plastic limit (PL)	Plastic index (PI)	Grain size
1	05°41′23″	06°27′40″	SB1	28	27	3.6×10^{-4}	34	4	30	Sandy clay
2	05°37′43″	06°29′41″	SB2	27	30	4.0×10^{-4}	38	2	36	Sandy clay
3	05°40′10″	06°28′30″	SB3	10	24	3.0×10^{-4}	25	NP	NP	Coarse grained sand
4	05°37′13″	06°25′00″	SB4	16	26	2.8×10^{-4}	26	NP	NP	Coarse grained sand
5	05°35′00″	06° 27′00″	SB5	45	37	4.8×10^{-4}	76	36	40	Silty clay
6	05°34′00″	06°27′01″	SB6	27	28	3.5×10^{-4}	33	3	30	Sandy clay
7	05°37′13″	06°25′00″	SB7	27	30	4.2×10^{-4}	38	3	35	Sandy clay
8	05°41′ 30″	06°27′40″	SB8	12	24	3.2×10^{-4}	24	NP	NP	Coarse grained sand
9	05°37′40″	06°26′30″	SB9	18	25	2.8×10^{-4}	26	NP	NP	Coarse grained sand
10	05°38′13″	06°25′00″	SB10	46	40	4.6×10^{-4}	76	35	41	Silty clay
				$\mu = 25.6$	$\mu = 23.70$	$\mu = 3.65 \times 10^{-4}$	$\mu = 40.00$	$\mu = 8.30$	$\mu = 21.20$	

μ mean, *SB* samples

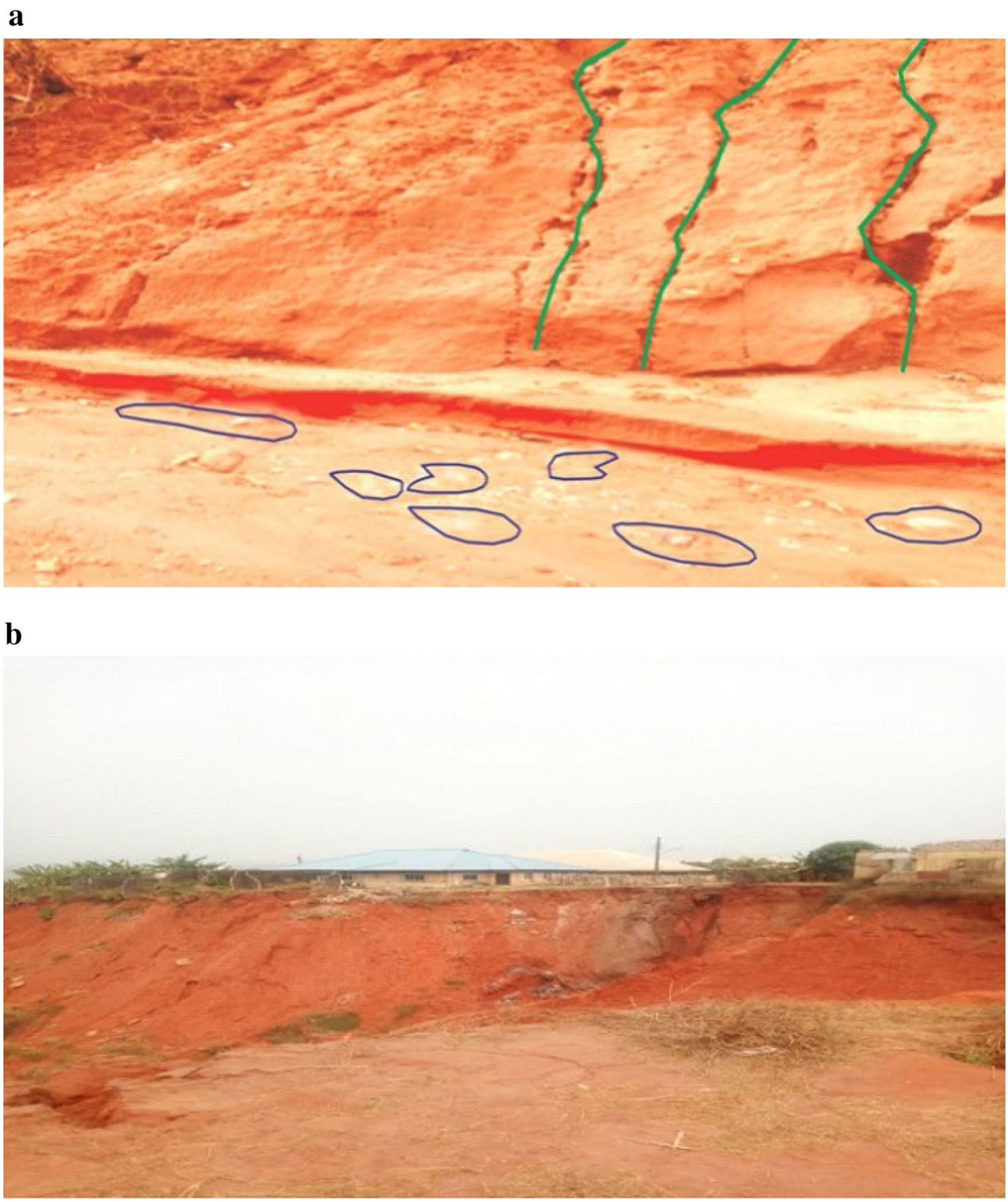

Fig. 7 a Cracks and fractures zones marked in green (photo by Aigbadon). **b** Surface water diverted to the landslides area couple with the poor drainage system (photo by Aigbadon)

material at the base. Subsequent weathering and mass soil sliding are as result of the weighted overburden laterite resting on the loosely compacted Ajali sands whose lateral base has been removed by erosion. The seepage-associated mechanism is also narrowed to cracks, burrows, and root holes. The development of gully channels interacts with the drainage of the inter-gully area through the gully beds and banks, redirecting surface and subsurface run-off which affects shallow landslides and gully erosion. Gulling infilling rates and the impacts of gully erosion in sediment yield contribute to landscape evolution (Fig. 10).

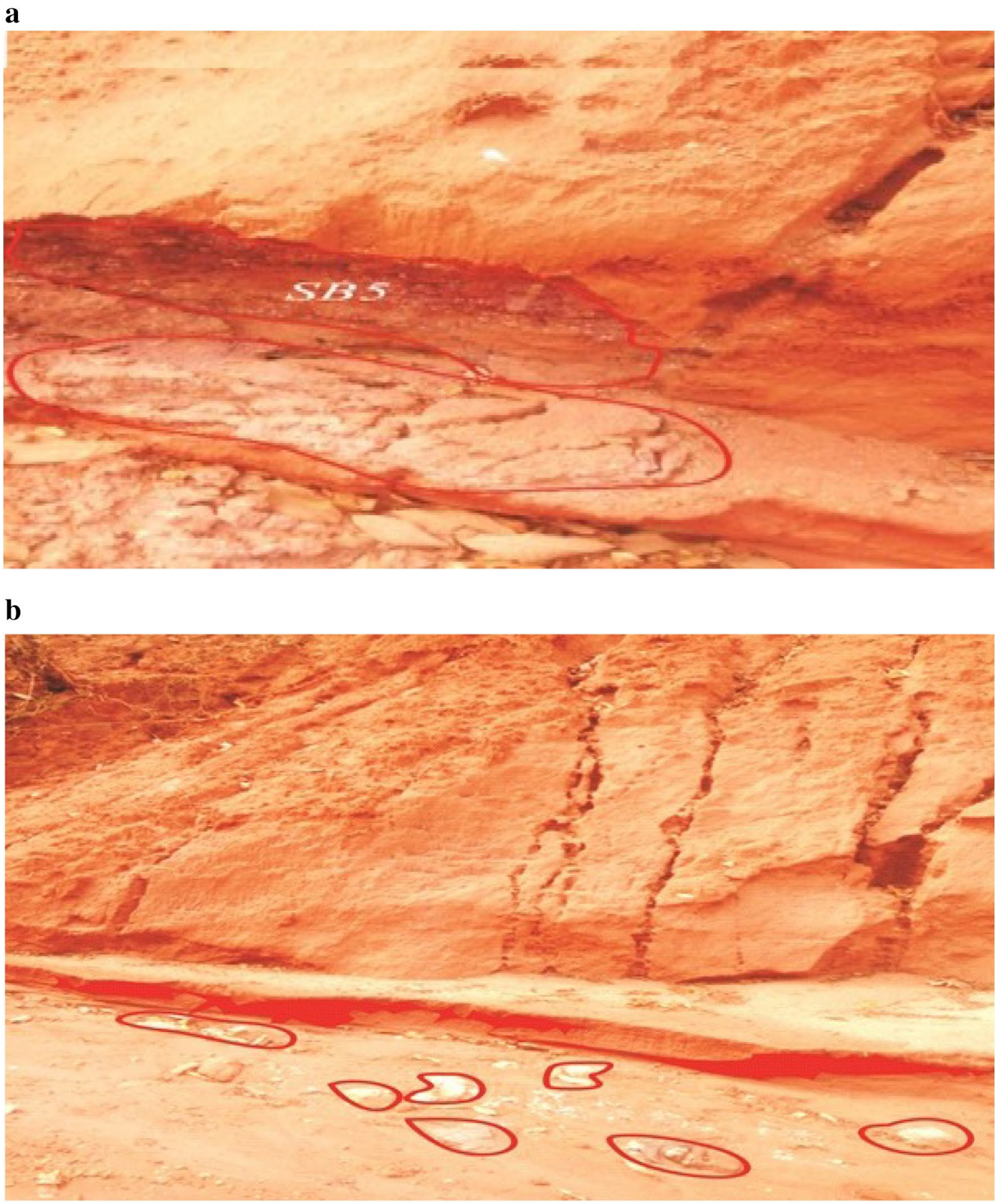

Fig. 8 **a** Shale/clay materials (SB5) acting as gliding surface in the study area (photo by Aigbadon). **b** Weathered shale/clay materials on the flood in the study area which act as the sliding plane in the affected areas (photo by Aigbadon)

Following those key findings, improving the drainage control and slope flattening will reduce the weight of the mass tending to slide and increase the resistance to sliding and hence increases the stability as recommended by (Egboka et al. 2019). The landslide areas should be covered with impermeable layers/materials and diverting the surface water away from the landslide areas. Gray and Sotir (1996) employed biotechnical slope stability method for slope failures and gully erosion problems. Such method should also be deployed in the study area to

Fig. 9 **a** Landslide on Iguosa area threatening lives and properties in the study area. **b** The road leading to various homes in the study area have be truncated by erosional activities (photo by Aigbadon)

avert and stop slope failures and erosion problems. Afforestation and re-vegetation of different resistance tree species should be planted on the sloping landscape. Construction of gravity and earth dams should be done to channel the flood, and this will help reduce the velocity of inflows and convey a large inflow of water away from different catchment areas around Iguosa and its surroundings into nearby natural basins or neighbouring Okhoro

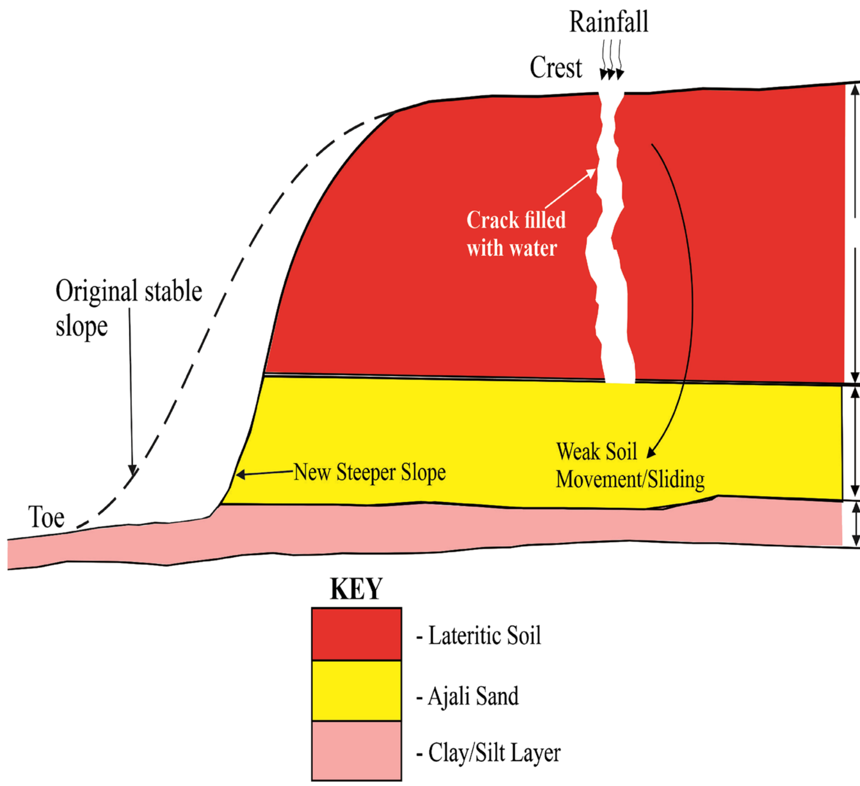

Fig.10 The mechanism of landsliding and gullies in the study area

River. Federal, State, and Local governments should enact laws to prevent the erection of structures in landslide-prone areas. Adopting these recommended mitigation measures will go a long way in reclaiming the affected lands, and solving the problems of failed slopes, and continuous expansion of landslide and gully erosion hazards in the study area.

Conclusions

The origin, associated mechanisms, and effects of landslides and gully hazards have been evaluated in Iguosa and its environs. Field observation reveals that the intense and prolonged rainfall, geomorphological characteristics, weakly developed structure, high slope instability, improper use of land, and the steepness of the slope, contributed to the origin of landslides and gully erosions 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 lithological units also contributed to landslide and gully erosion. Over four hundred and thirty-two houses, farmlands, and other physical properties have been damaged and abandoned. This study has recommended effective and efficient mitigation measures to tackle this menace by covering the landslide areas with impermeable layers/materials, diverting surface water away from the landslide areas, enacting laws to prevent the erection of structures on landslide-prone areas, sound drainage systems, the use of biotechnical slope and bioengineering methods.

Abbreviations

Kpa: 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.

Acknowledgements

I acknowledged Mr. Stanley Ajike for his assistance in generating the maps used in this study.

Authors' contributions

GOA: he led the team for the field investigation/mapping, data collection, data analysis, and drafting of the manuscript. AO, EOA: he supported the field investigation, data collection, data analysis, and writing of the manuscript. All authors read and approved the final manuscript.

Funding

This research work did not receive grants/funds from any agency, institution, or individual.

Availability of data and materials

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

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Received: 4 April 2021 Accepted: 2 July 2021
Published online: 19 July 2021

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