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Geological Assessment of Landslide Occurences in Okemesi Area, Southwestern Nigeria

Ayodele O. S.[1,*], Olayanju G. M.[2], Adeosun O. E.[1]

[1]Applied Geology Department, Federal University of Technology Akure, Nigeria
[2]Applied Geophysics Department, Federal University of Technology Akure, Nigeria

Abstract Landslide occurrence in Okemesi, an ancient town in the southwestern Nigeria on 24th of September 2017 was the third in the last two decades that led to loss of properties worth millions of Naira. This paper presents a geological investigation and quantitative modelling of the topographic surface of the area of landslide occurrence with the view of identifying the factors responsible for the land failure mechanism. The investigation included reconnaissance survey, geological mapping of the area to determine the underlying lithologic units, systematic sampling of soils and rocks at the affected sites at a sampling interval of 100 m, determination of geotechnical properties of the soils and rocks as well as Atterberg limits. Index and engineering properties of the soils such as load bearing capacities of the rocks and soils, repose angles and specific gravity were determined in the laboratory. The result of geotechnical analysis revealed that the soils are predominantly sandy clay with clay content ranging from 9.0 - 24.6%, sand content 60.2 – 70.6%, and silt content 13.5-24.6% respectively. The soils were classified as poorly graded on basis of the unified soil classification system with specific gravity ranging from 2.640 - 2.690. Laboratory estimated repose angles also range from 28.20 – 38.280, which indicated that analyzed soils showed high level of instability This can be attributed to the major damage caused by the slump at the toe and lower section of the slope during the 2017 landslide. It is therefore pertinent that the settlers be relocated to away from the schistose quartzitic hill to avoid loss of lives in future that might arise from possible reactivated landslide.

Keywords Okemesi, Landslide, Angle of Repose, Geotechnical properties, Rocks, Soil

1. Introduction

Alongside avalanche, landslide can be ranked as one of the natural disasters having high impact on humanity. In most cases, it occurs as landslip, slope failure or slump, which is an uncontrollable downhill flow of rock, earth, debris or the combination of the three. Landslides are among many disasters causing massive destructions and loss of lives and properties across the globe. A landslide can be defined as the movement of a mass of rock, debris, or earth down a slope. It is the collapse of a mass of earth or rock from a mountain or cliff. The mechanisms of rainfall-induced landslides have been extensively studied and some of the conclusions assert that the amount of rain, nature of slope-material, geology, discontinuities and weathering are the major factors predisposing a slope to failure ([9], [11], [12], [14] & [15]). The steepest angle at which the sloping surface of loose materials is stable is called the angle of repose. At this angle, the material on the slope face is on the verge of sliding. When the ground becomes saturated, it can become unstable, losing its equilibrium in the long run, which is when a landslide breaks loose. Other causes include factors that increase the effects of down-slope forces and factors that contribute to low or reduced strength. Much of the damage, according to Brabb (1989) [6] is masked by association with more spectacular events, such as earthquakes, volcanic eruptions, hurricanes, and floods. Landslide occurrences have been reported in various parts of Nigeria. This paper investigates the recurrent landslides in the area by determining the geotechnical properties of the soils and relate them to the geology of the area in order to identify plausible causes of the recurrent landslides in the area.

* Corresponding author:
osayodele@futa.edu.ng (Ayodele O. S.)
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2. Study Area

Agbona hill in Okemesi where the incident occurred lies within latitudes 7° 49' 0" N to7° 52' 30" N and longitudes 4° 53' 0" E to 4° 56' 30" E with a total surface area of 24km² (Figure 1). It lies in the eastern part of the Ilesha N.E topographical sheet No. 243 acquired at a scale of 1:50,000. The landslide occurred in two areas but only a part was quite accessible unlike the other parts which is thickly vegetated, steep and rugged thereby making accessibility difficult. There is prevalence of gully erosion along hill slopes and valleys while the drainage patterns of the study area are dendritic & Trellis.

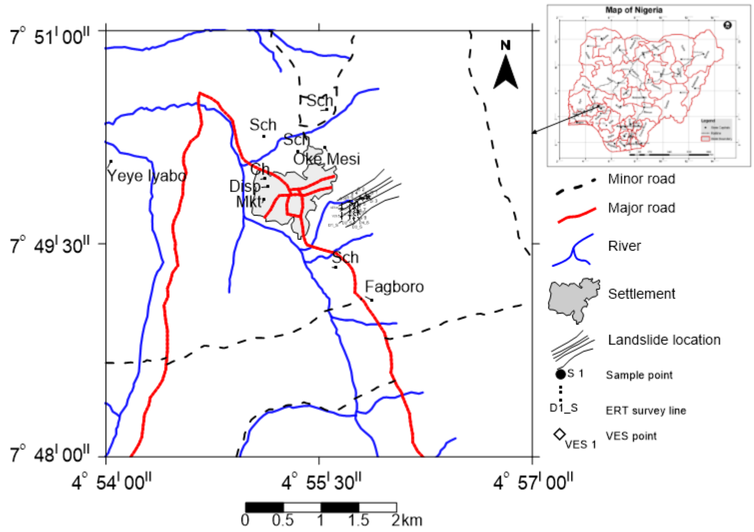

Figure 1. Map of the study area

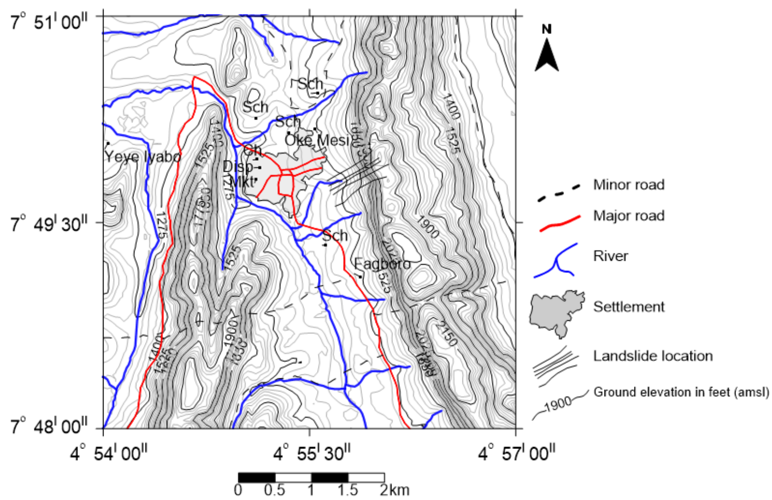

Figure 2. Topographic map of the study area

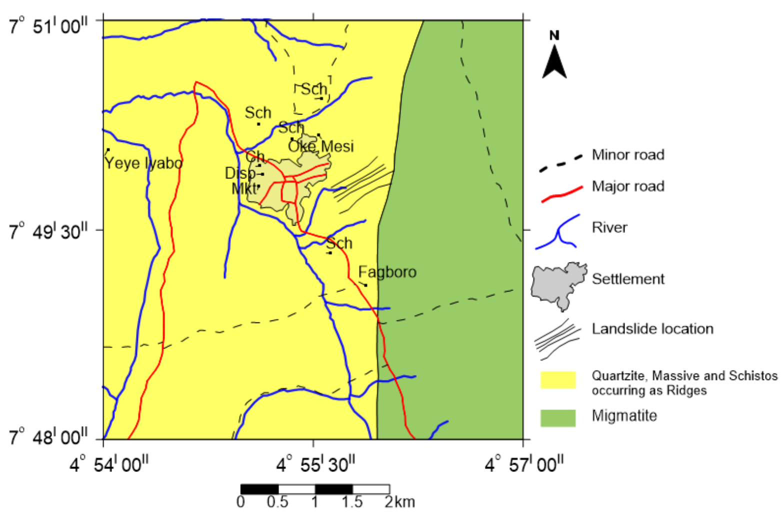

Figure 3. Geologic Map of the Study area (After Ayodele, 2018)

The area lies between two ridges running approximately north-south dominated by quartzite, quartz schists and quartzofeldspathic gneisses (Figure 2). The basement rocks are believed to be result of at least four major orogenic cycles of deformation, metamorphisim and re-mobilization corresponding to the Liberian (2,700Ma), the Eburnean (2,000Ma), the Kibaran (1,100Ma) and the Pan-African cycles (600Ma). The three first cycles were characterized by intense deformation and isoclinical folding accompanied by regional metamorphism, which was further followed by extensive migmitazition, granitization and gneissocity which produced syntectonic granites and homogenous gneisses. Late tectonic emplacement of granites and granitoids and associated contact metamorphism accompanied the end stages of the last deformation. The end of the orogeny was marked by faulting and fracturing [7]. The study area belongs to the Precambrian Basement complex of Southwestern Nigeria. The Basement rocks comprises of migmatite gneisses and a meta-supracrustal sequence. The western side is underlain by biotite gneiss, biotite schists, quartzites and associated pegmatites and gneisses, while the eastern side of the rock consists mainly of quartzites and quartz-schists (Figure 2). The quartzitic sequence, commonly referred to as the Effon Psammite Formation [10] occur mostly as massive quartzites, schistose quartzites and quartz schists which mostly make up the ridges of high relief typical of the study area. The rock sequences are of contrasting lithologies separated by the Ifewara fracture system. Also, the rocks in the study area had undergone polycyclic deformation and shearing, thereby causing the formation of both micro and macro structures in them such as foliations, fractures and folds of different magnitudes and styles. Others are micro-faults, joints, quartz veins, pegmatitic dykes and intrusions, solution holes, veins, veinlets and so on. These structures are observed to be the main factors controlling the drainage pattern in the area. However, the major fold, situated a few kilometres north of Okemesi Township, is a NNE-SSW trending antiformal structure, which was formed during the deformational phase of the Pan-African-orogeny [13]. Generally, these structures are obviously the product of Pan African orogeny that obliterated most of the earlier structures. The geological map of the study area is presented (Figure 3).

3. Methods

The method of study adopted for this research involved geologic field mapping and laboratory investigation. The field mapping exercise was carried out shortly after the event occurred. During the mapping, information on the landslides was gathered from eye witnesses. Geological mapping of the area was carried out to determine the nature of the rocks, the geological and environmental factors that must have caused the landslides and a special attention was paid to the rock types, fractures and human activities along the slope toe of the hill and types and sizes of the materials moved. Prior to the geological mapping exercise, aerial photographs taken in the 1970s and 80s and topographic maps of Okemesi-Ekiti, Sheet 244 Southeast and Southwest, on a scale of 1:50,000 were evaluated. The nature and amount of destruction to lives and property were recorded. A total of twenty (20) samples were collected from the study sites consisting both soil and rock samples (figure 4). The rock samples were collected at an interval of 100m and labeled before it was packed into the sample bag. Physical characteristics of the rocks such as color, textures and various features were recorded. The soil samples were collected at a depth of 1m and later subjected to index and strength tests to determine their geotechnical properties.

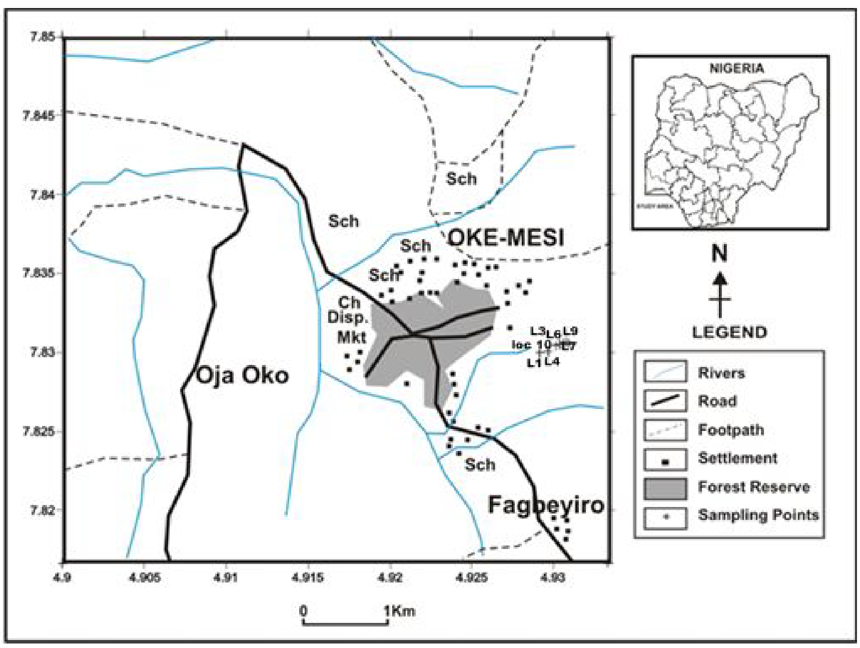

Figure 4. Map of the study area showing sampling points of rocks and soils

4. Results, Interpretations and Discussions

Results

Figure 5. Photograph of steep slopes that facilitated the movement of material down slopes

An eye witness account revealed that landslides occurred on the 24th September, 2017 in the morning between the hours of 1:00 am and 6:00 am after a torrential rain that lasted for three consecutive days. The sliding was accompanied by loud explosions and vibration that was felt in the surroundings. According to him, no life was lost but buildings were affected by the large boulders that were sliding towards the toe of the hill (Figures 5 & 6). The summary of geotechnical results is presented in table 1.

A typical grain size distribution curve of the tested soils are presented in figure 7. It shows that they are poorly graded as the soils are largely dominated by sand size particles. This is a reflection of the influence of the parent rock as the dominace of sand is expected from the weathering of quartzites.

Liquid limit ranges from 23.3 to 40.8% with the average of 34.04%; plastic limit ranges from 19.3 to 24.4% with the average of 22.35% and linear shrinkage range from 9.1 to 13.4% with the average of 7.16%. The positions of the samples are shown in figure 8.

Figure 6. Field Photograph of damaged building caused by the landslide

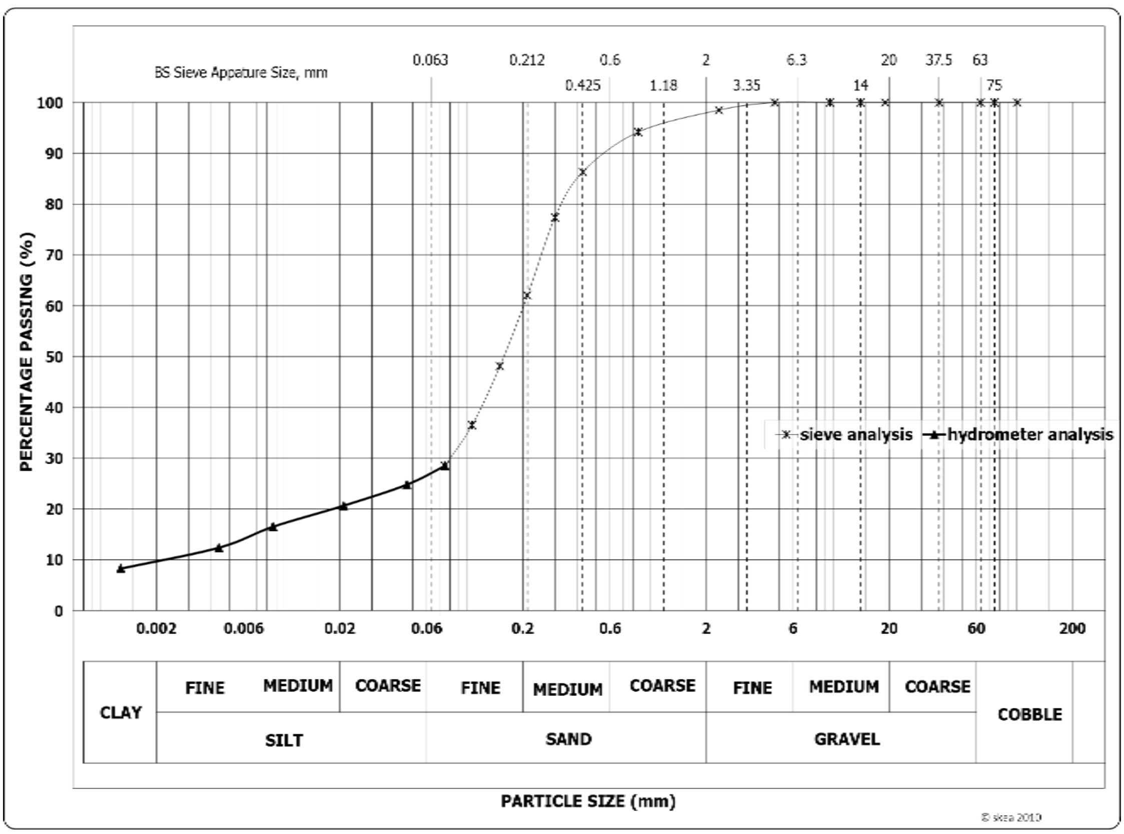

Figure 7. A typical grain size distribution curve of the study area

Table 1. The summary of geotechnical results

	Particle size distribution of the soils and their respective gradation expressions					Atterberg limits of soil samples and USCS classification scheme					Summary of results from Compaction Tests on soil samples		
S/N	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Soil grading	Liquid limit LL (%)	Plastic limit PL (%)	Linear shrinkage LS (%)	Plastic index PI (%)	USCS classification Scheme	Maximum Dry Density (g/cm3)	Optimum Moisture Content (%)	Specific Gravity
1	1.5	70.0	19.5	9.0	Poorly graded silty sand	23.3	19.4	2.9	3.9	SML	1926	13.8	2.668
2	1.4	70.6	13.5	14.5	Poorly graded clayey sand	27.1	19.3	5.7	7.8	SCL	1898	14.5	2.690
3	1.3	69.8	18.0	11.0	Poorly graded clayey sand	28.2	21.2	5.7	7.0	SCL	1761	18.0	2.658
4	1.5	69.7	15.5	13.3	Poorly graded clayey sand	29.3	21.1	5.7	8.2	SCL	1734	18.7	2.682
5	2.4	64.7	17.5	15.4	Poorly graded sandy sand	38.6	23.4	8.6	15.2	CI	1742	18.5	2.653
6	1.2	60.2	18.1	20.5	Poorly graded sandy sand	39.6	23.7	8.6	15.9	CI	1769	17.8	2.652
7	1.3	60.8	18.3	19.7	Poorly graded sandy sand	40.8	23.4	9.3	17.4	CI	1756	12.6	2.649
8	0.0	61.0	24.6	24.6	Poorly graded sandy sand	38.8	23.3	8.6	15.5	CI	1932	13.3	2.640
9	1.2	60.2	16.6	22.0	Poorly graded sandy sand	36.2	24.4	7.9	11.8	CI	1742	18.5	2.649
10	1.2	60.7	15.3	22.8	Poorly graded sandy sand	38.5	24.3	8.6	14.5	CI	1785	17.4	2.662

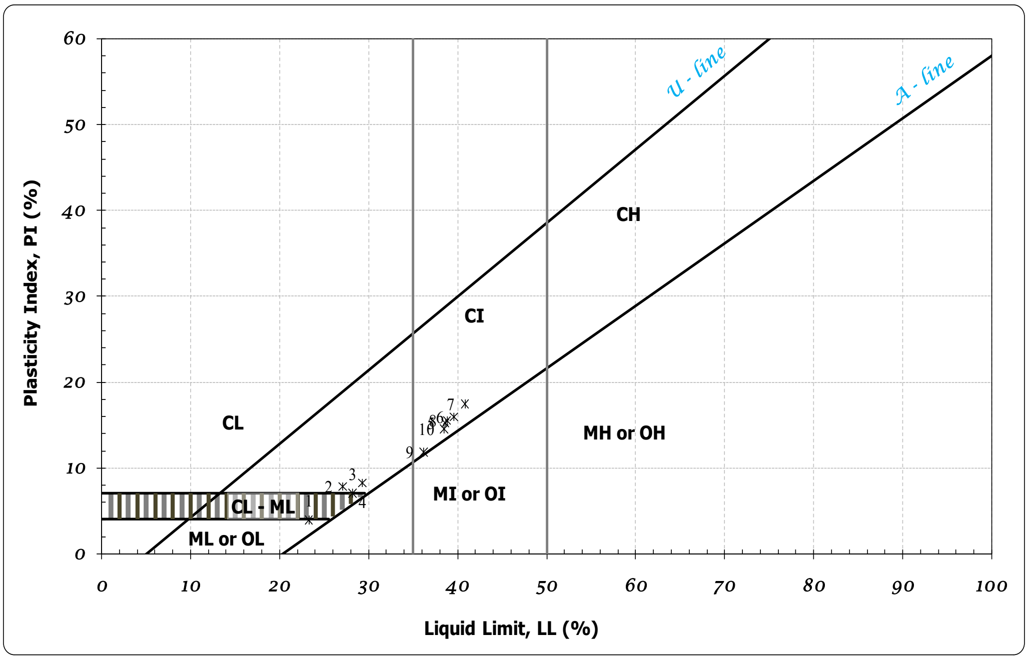

Figure 8. A typical cassagrande curve generated from the study soil

Figure 9 shows a typical compaction curves generated from the compaction test on the soil samples. Values of their maximum dry density and equivalent moisture content are as presented in Table 1. Maximum dry density ranges from 1734 to 1956g/cm^3 with the average of 1804.51956g/cm^3; the optimum moisture content ranges from 12.6 to 18.7% with the average of 16.31%. Based on this values, the soils are classified as sand with fair to poor characteristics as construction material used for embankment [3]. Overlapping values of the specific gravity and Maximum Dry Density is noted in most of the results. However, a wide range of values exists among those recorded for the values of Optimum Moisture Content. It is also noted that Maximum Dry Density increases with decrease in Optimum Moisture Content of the soils.

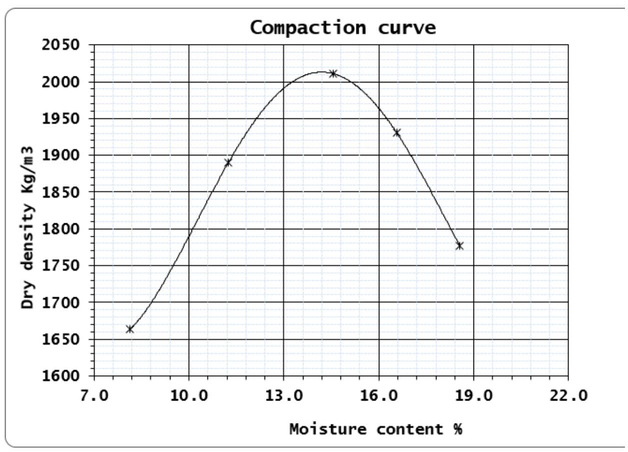

Figure 9. A typical compaction curve for the soil samples

Table 2. Rating of Soils Underlying the Study Area for use as subgrade, sub-base and base materials in road and airfield construction employing FMW&H rating

Location	Unsoaked CBR (%)	General Rating		Use
1	33	S6	Good	Sub- base
2	35	S6	Good	Sub- base
3	21	S5	Excellent	Sub- grade
4	22	S5	Excellent	Sub- grade
5	22	S5	Excellent	Sub- grade
6	21	S5	Excellent	Sub- grade
7	34	S6	Good	Sub- base
8	35	S6	Good	Sub- base
9	25	S5	Excellent	Sub- grade
10	21	Chart Area	Excellent	Sub- grade

Table 3. Classification of powder flowability based on angle of repose

Location	Angle of Repose (°)	Description
1	30.69	Good
2	34.08	Good
3	35.78	Fair
4	30.29	Good
5	38.28	Passable
6	30.68	Good
7	28.20	Good
8	35.65	Fair
9	32.51	Good
10	32.93	Good

Table 2 gives a summary of the Califonia Bearing Ratio (*CBR*) test. Gidigasu (1980) [8] confirmed *CBR* as the bonafide index of the bearing capacity for highway subgrade soils. The un-soaked *CBR* ranges from 21% to 35% with the average of 24.7% on the basis of the *CBR* values. Nevertheless, the soils have high water retention capacity, and adequate drainage is required to prevent ingress of water below, hence, there is a significant loss of strength in the soils causing failure of landslide.

UCS value ranges from 92.45 to 143.4kPa with the average of 126.065kPa. However, a wide range of values exists among those recorded for the values of unconfined compressive strength. It is also noted that there is increase Unconfined Compressive Strength with decrease in Sheer Strength of the soils.

Discussion of Results

Bamisaiye (2019) [5] noted that the volume of material generated by the landslide is 11, 441.5m^3 as calculated using the formula by Afatton et al (1991) [1]. The geotechnical properties employed in this study, revealed that most of the soil samples collected are of sand clay with a clay content ranging from 9.0 -24.6% and sand content varying from 60.2 – 70.6% and silt content varying from 13.5- 24.6%. Based on the Unified Soil Classification System [2], almost all the samples are classified as poorly graded. It follows that the information obtained from the particle size distribution curve can be used for predicting the soil water movement. The soil samples with less clay content are suspected to have more permeability to water, and therefore have more chances of causing landslide. The Atterberg limits were determined and are widely used for predicting the consistency of cohesive soil. The results obtained provide information about the soil strength behavior, stability, type and classification of organic or inorganic clay. Small range between the plastic limit and liquid limit value shows the ability of the samples to change from semi solid to liquid state resulting in significant decrease of cohesion and angle of internal friction and bearing capacity of soil after rain as explained. Specific gravity of the samples varied from 2.640- 2.690. The fairly high value of specific gravity was due to the absent of organic content in the soil samples. This is corroborated by the position of the soils on the cassagrande plasticity chart where they are classified as inorganic clays. The shear strength was observed by conducting unconfined compressive strength test, as the moisture content increases the shear strength value decreases showing that regular rainfall in less stable areas can easily create landslides. The repose angle of the slopes plays important roles in the stability of slopes. The repose angles can be classified as steep angle as they are close to 40% and the analyzed sample value range from 28.20 – 38.28° showing high level of instability (Table 3). The Carr classification of powder flow ability were used to classify the slopes into safe, state of impending failure and failed slopes.

5. Conclusions and Recommendations

Geological study as seen during the field mapping of the affected area shows that the rocks in the studied area has been intensely fractured. This has contributed to the occurrence of the landslide.

From the geotechnical properties of the soil samples analyzed the soil samples collected showed more susceptibility to landslide or slope failure. Remedial measure for earth slope stabilization includes reducing the height of the slope loading at the toe of the slope, benching, fattening or reducing the slope angle etc. The slopes should be improved on by methods like; drainage control, and slope flattening. The latter 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. Also, grouting and injection of cementing materials into weak zones also help in stability. This highlights the need for more rigorous analysis of the soil and subsequent adoption of appropriate prevention techniques. The mitigation method does not help in avoiding the landslide but helps to reduce the loss of life and damage to the property that can be caused due to the landslides.

Excavation activities should be avoided in regions that are highly susceptible to landslide or slope instability since that might trigger larger landslide especially in soft clays. In regions that are less susceptible to land slide the strengthening of slopes can be carried out with the help of plastic mesh reinforcement, proper drainage networks, check dams, constructing retaining walls, gabion walls etc. Providing vegetation on the slopes and other biotechnical slope protection methods like using geonets, planting vetiver etc. also helps in reducing the landslides.

Based on the findings of this research work, the following recommendations are made. (i) Excavation activities should be avoided in regions that are highly susceptible to landslide or slope instability since that might trigger larger landslide in the area. (ii) In regions that are less susceptible to landslide the strengthening of slopes can be carried out with the help of plastic mesh reinforcement, proper drainage networks, check dams, constructing retaining walls, gabion walls etc. (iii) Providing vegetation on the slopes and other biotechnical slope protection methods like using geonets, planting vetiver etc. also helps in reducing the landslides. (iv) Reforestation with deep rooted trees and planting trees in rows would help in reducing the landslides by enhancing stability.

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