SAJSET
ISSN: 2992-3581

Savannah Journal of Science and Engineering Technology
Volume: 03; Issue: 05; Pages: 338-345; 2025.
www.sajsetjournal.com.ng

DOI: xx.xxxx.x/sajset-03-2025-0040

SAJSET
ISSN: 2992-3581

Geotechnical and environmental assessment of some gully erosion sites in Girei and environs, Adamawa State, North-Eastern Nigeria

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Paper History
Received: 05th August, 2025
Accepted: 9th Sept., 2025
Published: September, 2025

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Abstract:
Gully erosion adversely affects farmlands and distorts ecological and social settings in many parts of Girei Local Government Area of Adamawa State. This paper assessed the geotechnical and environmental properties of gully erosion sites in the area to determine the causative factors. The study area experiences tropical climate with distinct rainy and dry seasons. It is underlain by Bima Sandstones; which contain quartz and feldspars, medium to coarse-grained, grade bedded and laminated. Thirty disturbed samples; collected at depths of 0.5m, 1.5m and 3.0m; from ten different gully sites were investigated. Laboratory tests results indicated that the gully sites soils are predominantly coarse sands (means: 45.05%, 44.7%, 47.6%) and fine sands (averages: 44.35%, 43.37%, 43.09%); with insignificant gravels, silts and clays percentages. The mean values of liquid limit, plastic limit and plasticity index are (25.07%, 23.63%, 22.85%), (16.16%, 14.67%, 13.98%) and (9.38%, 8.96%, 8.70%) respectively. The average natural moisture content values are 10.6%, 9.7%, 9.1% while that of specific gravity are 2.63; at all depths of sampling. The average values of maximum dry density, optimum moisture content and bulk density are (1.85 kg/m^3, 1.85 kg/m^3, 1.82 kg/m^3), (16.79%, 15.72%, 15.88%) and (1.74kg/m^3, 1.66 kg/m^3, 1.57 kg/m^3) respectively. The mean values of angle of internal friction are 25.4°, 25.4°, 25.8°; while that of cohesion are 2.9 KN/m^2, 2.4 KN/m^2, 2.2 KN/m^2. The results indicated the soils contain low amounts of fines. They are loose, non-plastic and highly instable soils. Consequently, they possess high void ratio, infiltration rates, flow velocities, seepage pressure and internal erosion potential. Hence, they are liable to effects of gully formation. Irregular/intensive rainfall, drought/ desertification, intensive bush clearing, repeated cultivations, and bush burning caused gully erosion in the study area. Positive farming practices and tree/grass planting are recommended for mitigation.

Keywords: Geotechnical properties, Gully erosion, Remedies, Shear strength

1. Introduction

Gully erosion is a visible form of soil erosion that reduces soil productivity, restricts land use, and threatens buildings, roads and fences [1]. They are relatively steep-sided water courses with clear form of soil degradation consisting of open, incised and unstable channels with depths more than 30 centimeters [2]. When soil is eroded from the gullied area, it results in siltation of fence lines, waterways, road culverts, dams and reservoirs; and clogging groundwater aquifers and polluting water courses [3]. Gully erosion is caused by concentration of surface run-off and flowing at high velocities to detach and transport soil particles, develop in watercourses; with far more capacity than they need to accommodate the run-off they are likely to carry [4]; it is caused by a combination of several factors which results in deep cuttings which dissects the entire land surface.

Environmental and pedological factors; guided by anthropogenic factors influence the extent of gully erosion [5]. Anthropogenic factors include land use, tillage methods and the nature of agro-technology. Vegetation clearance and over-grazing leave the soil bare; soil compaction by heavy machinery reduce the infiltration capacity of the soil and thus promote excessive water runoff and soil erosion. Soil type and rainfall are major factors of gully erosion. Soil erodibility is a product of geology and soil characteristics. Slope length and steepness are also serious attributes of gully erosion. Rainfall regime, a function of its intensity also contributes significantly to the erosivity [6]. The distribution, amount and intensity of rainfall in combination with other environmental factors contribute in accelerating the rate of gully erosion. Deforestation and agricultural activities expose the bare soils to erosion; subjecting the soil to different degrees of erosion. Geology influences soil nature and formation. Soil erodibility which is a measure of its susceptibility to particle detachment and transportation by agents of erosion; and physico-chemical properties of the soil; are all contributing factors. Anthropogenic influence arising from poor farming systems cause collapse of soil structure and accelerate runoff and soil loss; uncontrolled grazing result in deforestation; and indiscriminate foot paths created on the landscape form incipient channels. These factors often combine to weaken the soil; thus, causing it to become loose and slump under intensive rainfall; consequently resulting in gully erosion [7].

Many communities in Girei Local Government of Adamawa State are besieged by serious environmental degradation such as gully erosion. These problems adversely affect agricultural productivity and thus threatening food security. The ecological and social settings are often distorted leading to human and material losses. This research is aimed at ascertaining the contributing factors of this environmental hazard, by evaluating the geotechnical parameters and associated human activities that contribute to the genesis and expansion of these gullies; suggesting design for appropriate control measures.

2. Materials and methods

2.1 Physiography, climate and geology

Girei Local Government Area of Adamawa State, Nigeria falls between Latitudes 9° 20' - 9° 27'N and longitudes 12° 23' to 12° 27'E (Figure 1). The area experiences tropical climate characterized by two distinct seasons. The rainy season starts from in April and ends in October lasting for about six to seven months; with the months of August and September recording high rains; while March, April and October record low rainfall. Peak rainfall is usually recorded during the July – September period [8].

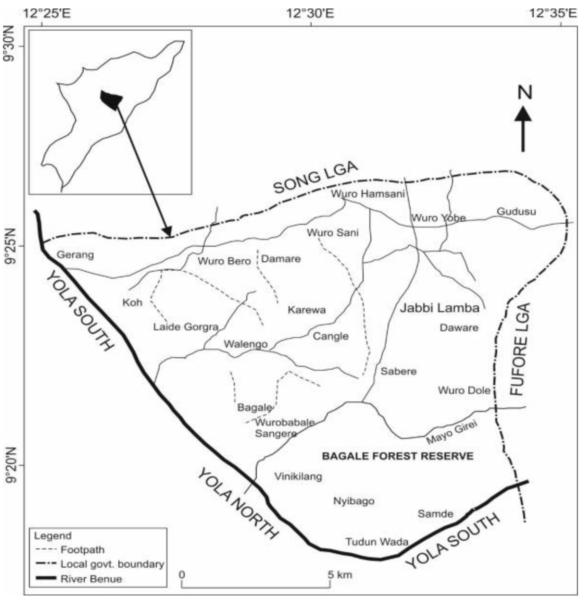

Figure 1: Location Map of the Study Area

The study area is within the hilly terrain of Bagale anticline and plains of Girei syncline. It is geologically underlain by Bima Sandstones of the Upper Benue Sedimentary Basin. These sedimentary rocks are part of the Yola arm of the Upper-Benue sedimentary basin. The rocks encountered during the field mapping are the Bima Sandstones; which are upper Albian in age and continental with thicknesses ranges from 300 m to 3,000 m. They are light brown, made up of quartz and feldspars, medium to coarse-grained, laminated and cross bedded [8].

2.2 Sample collection

The research which comprised field study and laboratory analyses was undertaken. During the field work, the area was traversed to gain access to sample locations; for the purpose of soil sampling and gully profile measurement. The inherent rock types were determined; as the residual soils are weathered products of the parent rocks.

Soils were sampled from incipient gullies at depths of 0.5m, 1.5m and 3.0m. Ten (10) gully wall profiles in ten (10) different identified gully sites were investigated. Personal observation and interviews were also done. A total of thirty (30) disturbed samples were collected in polythene bags and taken to the laboratory for geotechnical analysis. The laboratory tests were conducted at the Civil Engineering Department Laboratory of Adamawa State Polytechnic, Yola and were all performed in accordance with the specified standard procedures [9].

2.3 Soil physico-chemical and engineering properties

In the laboratory, soil parameters including grain size distribution, atterberg limits, natural moisture content, specific gravity, bulk density, and compaction characteristics (maximum dry density and optical moisture contents) were determined and measured. Soil engineering properties such as cohesion and angle of internal friction were also determined.

2.3.1 Grain size distribution analysis

From each sample, the percentages of gravel, sand, silt and clay contents were determined by conducting grain size distribution analysis; with the aim of finding the distribution of grain sizes within the soil samples.The apparatus used for this test include B.S Test Sieves, mechanical shaker, weighing balance and sieve brush. A sample was weighed and placed on selected sieves; which were placed on the mechanical shaker, followed by movement of the sieves and jarring action. The cumulative percentages retained and passing were then calculated.

2.3.2 Atterberg limit tests

These tests determine the effect of moisture content on the soil samples. Atterberg limits marked the boundaries of several state of consistency of plastic soil. Liquid limit, plastic limit and plasticity index are the parameters determined.

2.3.2.1 Liquid limit test

Liquid limit was determined with the aid of cone penetrometer. It is the moisture content at which the soil begins to behave like fluid under the influence of standard blows. A soil sample that passed through 425µm Sieve was first dried and broken down. A palette knife was used to mix the dried soil with water into a paste on a flat glass plate. The paste was then pushed with the palette knife into a cylindrical metal cup; which was leveled and placed under the cone penetrometer after it has been adjusted to point zero. The cone was then released to penetrate the soil and the reading was recorded. This was repeated till the soil failed or after five trials.

2.3.2.2 Plastic limit test

Plastic limit is the moisture content at which the soil begins to behave like plastic. A sample of dried soil passing the 425 µm Sieve was mixed with water on a glass plate until it is sufficiently plastic to be moulded into a ball. It was then rolled into 6mm diameter thread between the thumb and index finger; then further rolled into 3mm with some pressure between the finger – tips and a cleaned flat glass plate. The procedure was repeated until longitudinal and transverse crack appear at a rolled diameter of 3mm. The moisture content was determined after these cracks appeared. This procedure was carried out two times for each sample.

2.3.2.3 Plasticity index

Plasticity index is the range of soil moisture content over which the soil is plastic. It was determined by finding the difference between liquid limit, LL and plastic limit.

2.3.3 Natural moisture content (NMC) test

The natural moisture content NMC of soil is the ratio of the weight of water to the weight of the solids in a given soil mass; and gives an idea of the state of soil in the field. A known weight of samples were taken and weighed. It was then oven dried at a temperature of about 110°C for 24 hours and reweighed. The NMC (%) was calculated as shown in equation 1 [9]:

$$Moisture\ Content(w) = \frac{M_2 - M_3}{M_3 - M_1} \times 100(Mg/m^3) \quad (1)$$

Where M_1 = mass of container, M_2 = mass of wet soil + container, M_3 = mass of dry soil + container.

2.3.4 Specific gravity test G_s

Specific gravity is the ratio between the density of a soil sample and the density of water at 4°C. It is calculated using equation 2 after necessary measurements were taken [9].

$$Specific\ Gravity, G_s = \frac{M_2 - M_1}{(M_4 - M_1)(M_3 - M_2)} \quad (2)$$

Where M_1 = mass of conical flask, M_2 = mass of conical and soil, M_3 = mass of conical flask, soil and water, M_4 = mass of conical flask and water.

2.3.5 Bulk density test

Bulk density test was used to determine the weight per unit volume (kg/m^3) of loose dry soil sample. The apparatus used include a weighing balance, 1kg metal rod (18 inch), a flat-bladed knife and a cylinder of known weight and volume. The cylinder was filled with the soil sample, leveled with the flat-bladed knife and weighed without compaction; and emptied after the weighing. Five layered compaction was done with 1kg metal rammer on the sample in the cylinder and reweighed. These procedures were repeated three times for each sample and the bulk density for each sample was determined using equation 3 [9].

$$Bulk\ Density, \rho = \frac{W_2 - W_1}{V} \quad (3)$$

Where W_1 = weight of cylinder, W_2 = weight of cylinder and sample, V = volume of cylinder.

2.3.6 Compaction test

Compaction is the processes by which the moisture content change in soil is controlled, unit weight and shear strength are increased, and permeability is reduced; to make the soil less susceptible to settlement under load. The apparatus used consist of a known volume of mould with removable base, a detachable collar and a 2.5kg rammer. Three kg of air dried soil was used for the test and the test was repeated five times for each sample. The samples were mixed thoroughly before compaction and the moisture content used was between 4% - 20% of the weight of the sample. Three layers of compaction were done for each trial and 27 blows were done to compact each layer. The bulk and dry densities were calculated using equations 4 and 5 [9].

$$Bulk\ Density = \frac{M_1 - M_2}{1000}(Mg/m^3) \quad (4)$$

$$Dry\ Density, \rho_d = \frac{M_2 - M_1}{1000(1-m)} \quad (5)$$

Where M_1 = mass of mould (g), M_2 = mass of mould and compacted sample (g), 1000 = volume of mould (cm^3), m = moisture content used.

Rock work software was used in plotting the graphs of dry density, ρ_d against moisture content and the optimum moisture content OMC was determined. The dry density corresponding to the OMC is called the maximum dry density MDD.

2.3.7 Triaxial shear test

The shear strength properties of soil samples were determined using the consolidated undrained test. The OMC obtained from compaction test were used in preparing test samples of 50mm in diameter with a height to length ratio between 2 and 3. The samples were encased by a thin membrane and placed inside a plastic cylindrical chamber that was filled with water; and each was subjected to a normal stress or confining pressure (δ3) by compression of the fluid in the chamber. Deviator stress (load, δ1 – δ3) was applied constantly through a vertical loading ram. The cohesion and angle of internal frictional were determined the graph of normal stress using Rock work software and suffer 8 software.

3. Results and discussion

3.1 Geotechnical assessment of gully sites

Geotechnical parameters of gully erosion in different parts of Girei L.G.A of Adamawa State were assessed. The locations of the studied gully erosion sites are in Wuro-Dole, Jabbi-Lamba, Mallam-Madugu, Ruwo-Amsami and Jera-Bonyo (Figure 2a-2e). Others are in Sangere-MAU, Vunoklang, Damare, Bajabure and DagriWuro Alhaji (Figure 2f-2j).

Figure 2a: Gully erosion site at Wurodole, Girei

Figure 2b: Gully erosion site at Jabbi-lamba, Girei

Figure 2c: Gully erosion site at MallamMadugu

Figure 2d: Gully erosion site at Ruwo-Amsami

Figure 2e: Gully erosion site at Jera-Bonyo

Figure 2f: Gully erosion site at Sangere-MAU

Figure 2g: Gully erosion site at Vunoklang

Figure 2h: Gully erosion site at Damare

Figure 2i: Gully erosion site at Bajabure

Figure 2j: Gully erosion site at DagriWuro Alhaji

The depth of these gullies ranges from 0.5m to 3.3m while their widths of the gullies vary from 1.75m to 3.456m. The geotechnical parameters of thirty (30) soil samples from ten (10) gully erosion sites (3 samples in each) in the study area at depths of 0.5m, 1.5m and 3.0m were analyzed. The summary of the results is presented in Tables 1 and 2.

Table 1: Summary of Geotechnical properties of soil samples in the study area

Parameters	**Location**														
	Wuro-Dole			**Jabbi-Lamba**			**Mallam-Madugu**			**Ruwo-Amsami**			**Jera-Bonyo**		
Depth(m)	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0
Gravel (%)	0.50	0.40	1.80	0.0	4.00	2.50	3.70	4.50	3.70	0.51	0.44	1.85	0.60	3.70	2.55
Coarse Sand (%)	42.7	44.1	46.2	46.5	48.2	44.7	39.8	47.5	46.6	41.6	42.3	47.7	47.0	48.4	45.7
Fine Sand (%)	53.8	52.5	44.7	42.5	41.8	45.3	44.2	43.3	47.1	54.6	51.7	46.4	41.5	40.8	45.8
Silt (%)	1.78	1.81	1.65	6.3	3.9	4.1	4.3	3.8	2.8	1.66	2.85	1.85	7.3	4.9	4.4
Clay (%)	1.22	1.19	2.15	4.7	2.1	0.9	1.7	1.2	1.2	1.63	2.71	2.20	3.6	2.2	1.55
LL (%)	24.2	23.6	25.3	26.6	23.5	22.4	22.5	21.2	20.7	25.1	24.2	25.0	25.7	24.5	22.6
PL (%)	21.4	20.7	18.8	15.8	15.6	14.6	13.5	12.8	11.9	20.7	21.2	19.7	12.9	14.8	15.8
PI (%)	2.8	2.9	6.8	15.2	7.9	7.8	9.0	8.4	8.8	4.4	3.00	5.3	12.8	9.7	6.8
Bulk Density (Mg/m^3)	1.82	1.74	1.62	1.72	1.64	1.52	1.54	1.44	1.42	1.82	1.74	1.62	1.72	1.64	1.52
MDD (Mg/m^3)	1.84	1.96	1.80	1.81	1.83	1.82	1.90	1.88	1.80	1.76	1.88	1.84	1.82	1.78	1.80
OMC (%)	16.4	14.5	15.6	16.6	16.4	15.5	16.7	15.4	15.5	16.8	15.3	16.2	16.8	15.4	16.5
NMC (%)	12.5	12.1	11.5	12.4	11.4	11.7	10.9	8.8	7.9	12.3	12.4	11.2	12.2	12.6	11.4
Cohesion(KN/M^2)	2.0	2.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	2.0	3.0	3.0	2.0	3.0
AIF (°)	24	25	26	24	27	26	25	24	27	26	24	25	26	25	24

Where LL = Liquid Limit, PL = Plastic Limit, PI = Plasticity Index, G_s = Specific Gravity, OMC = Optimum Moisture Content, AIF = Angle of Internal Friction.

The textural characteristics of the sampled soils shown in Tables 1 and 2 at the gully erosion sites show that the gravel fraction at depths of 0.5m ranges from 0.0% to 9.0%, with a mean of 3.17%; at depths of 1.5m from 0.44% to 7.0% with a mean of 3.15%; while at depths of 1.5m from 1.8% to 7.0% with a mean of 3.72%. Coarse sand fraction at depths of 0.5m it ranges from 39.8% to 51.6% with a mean of 45.05%; at depths of 1.5m from 42.3% to 52.2% with an average of 47.71%; and at depths of 3.0m from 44.7% to 52.5% with a mean of 47.6%. Fine sand fraction at depths of 0.5m it ranges from 38.8% to 53.8% with an average of 44.35%; at depths of 1.5m from 40.8% to 52.5% with a mean of 43.37%; while at depths of 3.0m from 38.5% to 47.8% with a mean of 43.09%. Silt fraction at depths of 0.5m it ranges from 1.66% to 7.30% with a mean of 4.50%; at depths of 1.5m from 1.81% to 4.90 with an average of 3.63%; and at depths of 3.0m from 1.65% to 4.8% with a mean of 2.97%. Clay fraction at depths of 0.5m it ranges from 1.10% to 4.70% with an average of 2.37%; at depths of 1.5m from 1.10% to 2.71% with a mean of 1.77%; while at depths of 3.0m from 0.90% to 2.15% with a mean 1.54%.

The results of grain size distribution analysis did not indicate significant differences across the sampling depth in the soil textural characteristics. The bulk of the soils in all the sampled locations are the sandy; which might have contributed to their being susceptible to gully erosion [10]; probably due to high rate of infiltration rate. The low percentages of silt and clay materials; which would have cemented the sand particles indicate that the soils are non-plastic; implying in-sufficient binding materials and low cohesion[11]. These might have resulted to the ease with which erosion occurs in the study area.

3.2 Atterberg Limits

From Table 1 and Table 2, the Liquid Limit values of the samples obtained at depths 0.5m that range from 22.5% to 26.2% with a mean of 25.07%. They range at depths 1.5m from 21.2% to 25.4% with an average of 23.63%; and at depths of 3.0m from 20.4% to 25.3% with a mean of 22.85%. The plastic limit values at depths 0.5m range from 12,9% to 21.4% with a mean of 16.16%; at depths of 1.5m from 11.5% to 21.2% with a mean of 14.67%; while at depths of 3.0m from 9.7% to 19.7% with an average of 13.98%. The plasticity index values at depths of 0.5m range from 2.8% to 15.2% with a mean of 9.38%; at depths of 1.5m from 2.9% to 12.7% with an average of 8.96%; and at depths of 3.0m from 5.3% to 12.0% with a mean of 8.70%.

Table 2: Summary of Geotechnical properties of soil samples in the study area

Parameters	**Location**														
	Sangere-MAU			**Vunoklang**			**Damare**			**Bajabure**			**DagriWuro Alhaji**		
Depth(m)	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0	0.5	1.5	3.0
Gravel (%)	4.00	7.00	7.00	9.00	7.00	3.60	3.70	3.30	3.30	4.50	5.00	6.30	5.20	3.20	4.60
Coarse Sand (%)	43.2	44.8	51.0	50.3	51.7	52.5	44.9	47.3	45.7	43.2	45.6	50.6	51.6	52.2	51.5
Fine Sand (%)	44.8	44.2	39.0	33.7	34.3	37.5	43.8	44.1	47.8	45.8	44.3	38.8	38.4	38.7	38.5
Silt (%)	4.9	2.5	1.8	5.2	4.9	4.8	6.5	4.2	1.7	3.9	3.7	2.8	3.2	3.7	3.8
Clay (%)	3.1	1.5	1.2	1.8	2.1	1.6	1.1	1.1	1.5	2.6	1.4	1.5	1.6	2.2	1.6
LL (%)	25.8	23.3	20.9	25.9	24.4	22.5	23.7	21.9	20.4	26.2	24.3	22.2	25.3	25.4	24.5
PL (%)	15.7	12.6	12.3	15.3	11.7	11.9	13.8	11.5	9.7	16.6	13.1	12.6	15.9	12.7	12.5
PI (%)	10.1	10.7	8.6	10.6	11.7	10.6	9.9	10.4	10.7	9.6	11.2	9.6	9.4	12.7	12.0
Bulk Density (Mg/m^3)	1.82	1.78	1.68	1.78	1.72	1.64	1.54	1.44	1.42	1.82	1.78	1.68	1.78	1.72	1.64
MDD (Mg/m^3)	1.87	1.83	1.84	1.86	1.82	1.81	1.92	1.84	1.82	1.85	1.80	1.82	1.88	1.84	1.86
OMC (%)	16.5	16.3	15.7	16.4	16.3	15.2	17.4	15.8	16.3	17.5	16.6	15.9	16.8	15.2	16.4
NMC (%)	8.9	7.8	6.9	8.7	6.7	6.6	10.5	9.4	8.4	9.5	7.5	7.6	8.6	7.8	7.6
Cohesion(KN/M^2)	3.0	3.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	3.0	2.0
AIF (°)	26	25	27	26	24	27	26	27	25	24	26	25	27	25	26

Where LL = Liquid Limit, PL = Plastic Limit, PI = Plasticity Index, G_s= Specific Gravity, OMC = Optimum Moisture Content, AIF = Angle of Internal Friction.

Liquid Limit, Plastic Limit and Plasticity Index of soil; all depend upon the content, type and amount of clay; they give indication of the consistency of the soil. The low value of liquid limit of the soils is attributed to low amounts of fine fraction and indicates that the soil may change from one state of consistency to another with minimum change in water content [12]. The PI is a measure of the fineness of the particles of a soil mass [4], [13]. All the soil samples recorded low plastic limits and liquid limits; consequently low plasticity. The low values of their plasticity index also indicate that they are relatively unstable; because sub-soil unit with the least plasticity index will have the highest instability. These indicated that the soils are non-cohesive; water flows through with ease and moves the soil particles down slope with increase in velocity [13].

The results of natural moisture content (NMC) test (Table 1 and Table 2) revealed ranges at depths 0.5m from 7.8% to 12.5% with a mean of 10.6%; at depths 1.5m from 6.7% to 12.6% with an average of 9.7%; and at depths 3.0m from 6.6% to 11.7% with a mean of 9.1%. The low NMC recorded in all the sampled soils is due to low clay content in all the samples. The NMC values decrease with depth; probably because the NMC parameter of soil is a function of rainfall intensity, depth of sample collection and soil texture [7].

The specific gravity (G_s) values for the studied soil samples (Table 1 and Table 2) at depths 0.5m range from 2.58 to 2.66 with a mean of 2.63; at depths 1.5m from 2.60 to 2.66 with an average of 2.63; while at depths 3.0m from 2.59 to 2.66 with a mean of 2.63. The G_s is used as a measure of the degree of soil maturity. According to [14], lower specific gravity values indicate a coarse soil, while higher values indicate a fine grained soil. The G_s values recorded by the studied soils might be attributed to some percentage of organic matter presence in the samples [15].

The results of compaction test (Table 1 and 2) show that the optimum moisture content (OMC) of samples obtained at depths 0.5m range from 16.4% to 17.5% with a mean of 16.79% and the maximum dry density (MDD) range from 1.76 kg/m^3 to 1.92 kg/m^3 with an average of 1.85 kg/m^3. At depths 1.5m, the OMC range from 14.5% to 16.6% with a mean of 15.72% and the MDD range from 1.78 kg/m^3 to 1.96 kg/m^3 with a mean of 1.85 kg/m^3. At depths 3.0m, the OMC range from 15.2% to 16.5% with an average of 15.88% and the MDD range from 1.80 kg/m^3 to 1.86 kg/m^3 with a mean of 1.82 kg/m^3.

Compaction test increase soil's strength and prevent seepage of water through it. Both soil water content and the dry density affect soil strength; which will increase when the soil is compacted to a higher density and when the soil looses water, dries and hardens [16]. The compaction results indicated that both the OMC and MDD values are low and that the soils are considered loose with little amount of clay as binding material [11].

The results of bulk density test shown in Table 1 and Table 2, revealed that the values range at depths 0.5m, from 1.54kg/m^3 to 1.82kg/m^3 with a mean of 1.74kg/m^3; at depths 1.5m from 1.44 kg/m^3 to 1.78 kg/m^3 with an average of 1.66 kg/m^3; while at depths 3.0m from 1.42 kg/m^3 to 1.68 kg/m^3 with a mean of 1.57 kg/m^3. These showed that the bulk densities of the soil samples are relatively low, poorly consolidated and therefore prone to short dispersion times [17]; hence the soils are loose and accounts for the high void ratio; which lead to high infiltration rates, high flow velocities, high seepage pressure and high internal erosion potential. This suggests that the soils are susceptible to easy dispersal by flood waters and subjected to tremendous buoying. Soils consisting of sands with low clay content, low bulk density, and high void ratio are usually susceptible to erosion [18].

Triaxial test was used to determine the shear strength properties of soil samples. The results obtained (Table 1 and 2) show that at depths 0.5m the angle of internal friction (AIF) range from 24° to 27° with a mean of 25.4° and the cohesion range between 2.0 KN/m^2 to 3.0 KN/m^2 with an average of 2.9 KN/m^2. At depths 1.5m, the AIF vary from 24° to 27° with an average of 25.4° while the cohesion range from 2.0 KN/m^2 to 3.0 KN/m^2 with a mean of 2.4 KN/m^2. At depths 3.0m, the AIF range between 24° and 27° with an average of 25.8°; while the cohesion vary from 2.0° to 3.0° with an average of 2.2°. These values are low and can offer little resistance to the effect of both surface water and subsurface flow [17]. Based on their cohesion and AIF, the soils are slightly hard but not strong enough to resist forces of erosion. It appears that the shear strengths of the soil samples are uniform across the profile. Hence the medium cohesive top soil assist in initiating the gully process by encouraging overland flows that lead to the formation of rills and eventual gullies.

3.3 Causes of Gully Erosion:

Based on field observations and interaction/interview with residents, some of the most likely causes of gully erosion in Girei and the surroundings areas are:

a. Poor ground cover due to intensive bush clearing, repeated cultivations bush burning.
b. Desertification and drought.
c. Channeling and concentration of runoff from steep lands into cleared lands.
d. Poor and unstable soil in drainage lines.
e. Irregular and intensive rainfall.

3.4 Mitigation and Remedies

Gully erosion mitigation and management should be adapted towards changing the slope characteristics of the area so as to decrease the amount and velocity of run-off [20]. Agricultural practices such as bush burning, over cultivation and over grazing which tend to strip off the vegetation cover of the soil should be stopped or minimized [16]. Massive planting trees and grasses high rate of survival; which can intercept raindrops and decrease the speed with which they hit the unconsolidated earth; should be encouraged to forestall eliminate or control gully erosion initiation and development [6].

4. Conclusion

The textural properties of the residual soils are sandy with insignificant percentages of gravels, silts and clays.

The average gravel fractions are 3.17%, 3.15% and 3.72%; the mean of coarse sand fractions are 45.05%, 44.7% and 47.6%; the mean of fine sand fractions are 44.35%, 43.37% and 43.09%; the mean of silt fractions are 4.50%, 3.63% and 2.97%; while the average of clay fractions are 2.37%, 1.77% and 1.54%; at depths of 0.5m, 1.5m and 3.0m respectively.

The means of liquid limit LL values are 25.07%, 23.63% and 22.85%; the average plastic limit PL values are 16.16%, 14.67% and 13.98%; and the means of plasticity index PI values are 9.38%, 8.96% and 8.70%; at depths of 0.5m, 1.5m and 3.0m respectively. The low values of LL, PL and PI in the soil samples is attributed to low amounts of fine fraction; which consequently indicated that possess low plasticity and high instability.

The average natural moisture content NMC values are 10.6%, 9.7% and 9.1% at depths of 0.5m, 1.5m and 3.0m respectively. The NMC values decrease with depth and did not approach the LL. The low NMC recorded in all the sampled soils is due to low clay content in all the samples. The average specific gravity G_s values for soil samples are 2.63; at all depths of sampling. This indicates that the soils are slightly coarse and contain some percentage of organic matter.

The average values of maximum dry density MDD are 1.85 kg/m^3, 1.85 kg/m^3 and 1.82 kg/m^3; while the optimum moisture content OMC mean values are 16.79%, 15.72% and 15.88%; at depths of 0.5m, 1.5m and 3.0m respectively. These indicated that both the OMC and MDD values are low and that the soils are considered loose with little amount of clay as binding material. The average values of bulk density for the studied soils are 1.74kg/m^3, 1.66 kg/m^3 and 1.57 kg/m^3; at depths of 0.5m, 1.5m and 3.0m respectively. These low values indicated that the soils are loose with high void ratio, high infiltration rates, high flow velocities, high seepage pressure and high internal erosion potential. The mean values of angle of internal friction AIF are 25.4°, 25.4° and 25.8°; while the average cohesion values are 2.9 KN/m^2, 2.4 KN/m^2 and 2.2 KN/m^2; at depths 0.5m, 1.5m and 3.0m respectively. These low values indicated uniform shear resistance across the profile; the soils offer little resistance to the effect of water flow; hence encourage formation of rill and gully erosion.

The geotechnical results of the soil samples indicate that the susceptibility of the materials to gully formation is due to its highly weathered nature and low fines (silt and clay). The results further revealed that the soils in the study area have low plasticity, not-compact, cohesionless, penetrable, and have less ability to resist shear deformation stresses. A combination of several factors such as irregular and intensive rainfall, desert encroachment, drought, removal of ground cover due to intensive bush clearing, repeated cultivations bush burning, concentration of runoff from steep lands into cleared lands and poor/unstable soils in drainage lines caused the menance of gully erosion in the study area.

Recommendations

To mitigate and remedy gully erosion, the slope characteristics of the area need to be changed to decrease the amount and velocity of run-off, bush burning, over cultivation and over grazing should be stopped or minimized and trees and grasses with high survival rate should be planted.

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