

QUANTIFICATION OF GULLY EROSION IMPACT IN SUDAN SAVANNAH AREAS OF KEBBI STATE, NIGERIA

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ABSTRACT

Gully erosion is a global threat to soil and food security. It is a serious problem to soil and land management in Africa. This study is aimed at measuring the quantitative impact of gully erosion and to evaluate the soil quality, soil fertility and land suitability around Argungu, Augie, Birnin Kebbi and Gwandu areas of Kebbi State, Nigeria. Sixty-four (64) soil samples were collected and assessed from the sixteen (16) different sites in the study areas. The results shows that of these 16 sites, more than half (13 sites) were critically damaged. The highest value of soil volume loss (796647.2 m^3) was recorded at Gwandu whereas the lowest (241.60 m^3) was recorded at Augie. The maximum width (49.56 m) was recorded at Tarasa and minimum (1.01 m) at Argungu 2. Likewise, maximum depth (8.666 m) was recorded at Badariyya and minimum (0.94 m) was recorded at Argungu1. Land and soil quality were characterized as bad and not suitable for agriculture. Significant portion of lands appeared to be vulnerable to landslides and further surface soil damage. Results also shows that the natural soil structural units, which were evaluated as granular, massive and single-grains appeared to have massive, small polyhedrals, very irregular, non-coherent, loose and poorly coordinated. It was observed that these characteristics of the study sites played a major role on the drainage pattern for gully erosion impact, and probably predicted high risk of soil quality deterioration and total surface soil damage in the near future. The study further suggested the use of technological and agronomic soil management options, which include the adoption of multiple scientific and cultural approaches such as planting of shelter belts across the affected sites, advanced drainage systems and provision of water ways, as well as inter- and mixed cropping systems among others.

Keywords: Soil erosion, Gully erosion, Land suitability, Soil depth, Soil width, Soil quality

1. INTRODUCTION

Soil condition in the Sudan savannah of Kebbi State, around Augie, Argungu, Birnin Kebbi and Gwandu areas are physical affected by soil erosion (Usman, 2016). The physical impact of soil erosion in the region was considered nuisance to both soil resource and surface soil quality (Usman et al., 2016). This soil erosion impact is a threat to food security and rural-urban economic development in sub-Saharan Africa (Usman et al., 2017). Soil erosion impact placed a serious concern on the physical, biological and chemical components of soil and soil biodiversity (Al-Shoumik et al., 2023). It has caused surface soil damage; decreased size of land for potential agriculture and economic growth and enhanced food security in sub-Saharan Africa (Ezeh et al., 2024). Soil erosion forced the surface soil particles to detach and damaged soil structural quality and creates gully channels (Gebrie et al., 2023). The detachment of soil particles was looked as one of the vicious environmental problems reducing the potential productivity and health condition of agricultural soils in sub-Saharan Africa (Andualem et al., 2023). In Sudan savannah zone of Kebbi State, this detachment of soil particles by erosion, has been described as the removal of the soil materials from the top surface soil layer (sheet), extending to smaller channels (rills), and intensifying to larger channels (gullies) (Usman et al., 2024a). Baade et al. (2024) described the initial rate of this removal of surface soil materials as a form of depression by rainfall impact (splash erosion) which can be extended to sheet, rill and gully erosion due to factors such as poor vegetation cover, climate change impact and poor soil management adaptation. The metaphors of how concentrated these types of erosion are, depends largely on the nature and condition of the soil properties, slope, vegetation cover and land use activities (Usman and Jayeoba, 2024). Land areas subjected to continuous cultivation without proper soil management, lack of tree plantation and mismanagement of vegetation (shrubs and plants), are considered as important factors leading to soil erosion in the Kebbi State (Usman, 2016). Evans (2013) noted that surface soil materials can be washed away easily by rains under poor vegetation cover and poor management practices. The problem in this situation has been described to affect soil quality and surface soil fertility at both on-site (detached site) and off-site (deposited site) areas (Lugato et al., 2016). This problem of soil erosion remained a serious challenge to agricultural soils in Africa and the cost implication is significant to economic development of the region (FAO, 2023).

The process of soil erosion is generally caused by combination of natural erosive agents, which include rainfall, wind, waves and bioturbation including human-induced factors such as overploughing, overgrazing, building, deforestation, forest fires and off road vehicles (Pandey et al., 2016). These combinations of erosive factors appeared to have physically caused serious surface soil damages and bigger gully channels to occur in many areas around Augie, Argungu, Birnin Kebbi and Gwandu areas of Kebbi State (Usman et al., 2016). The impact of climate change especially in very poor vegetation areas is believed to have increased the width and depth of gully erosion in sub-Saharan Africa (Usman et al., 2024b). This deepening of gullies in the affected areas, increase the cost of conservation application, reduce land quality, affect soil productivity, cause food insecurity, pressurize the soil biological biodiversity, and create hazards to human accommodation and wellbeing (Yang et al., 2023). Reduction in agricultural land size and soil functional service to support the production of food crops, were noted to occurred as a result of soil erosion in dryland areas of Kebbi State (Usman et al., 2016). This could also lead to rural-urban migration, increase hunger, malnutrition and land scarcity in the area (Usman, 2013). However, it is evident that gully erosion is deeper and cannot be managed by ploughing (Usman, 2024a). These problems caused by erosion, placed an urgent call for assessment and modelling of soil erosion in the affected areas (Borrelli et al., 2021; Andualem et al., 2023; Ezeh et al., 2024). Therefore, assessment of soil erosion in the affected sites of Augie, Argungu, Birnin Kebbi and Gwandu areas of Kebbi State is important (Usman et al., 2020). This will help to provide soil data required for the adaptation of appropriate soil conservation in the affected areas of the State (Jat et al., 2023). This study aimed to assess and evaluate the impact of gully erosion in four local government areas of Kebbi State, Nigeria. The specific objectives are: (a) measure the quantitative impact of gully erosion, (b) evaluate the soil quality and land suitability and (c) evaluate the soil fertility status of the affected sites.

2. MATERIALS AND METHODS

Study area and sites characteristics

Kebbi State is geographically located in north-west Nigeria and dominated by Hausa-Fulani who are largely depended on farming and rearing of animals. The State has a total land area of 36,229 km² of which 12,600 km² is under cultivation (Usman, 2013). The two important agricultural lands in the State are dryland and Fadama. Significant parts of these two lands are located in the Sudan savannah zone of the State (Usman, 2016). The four local government areas of the Sudan savannah zone covered under this study are Augie, Argungu, Birnin Kebbi and Gwandu. The zone lies between latitude 11° and 13°N and longitudes 4° and 12°E, and bordered the Nigerian States of Sokoto to the north and Zamfara to the east (Figure 1).

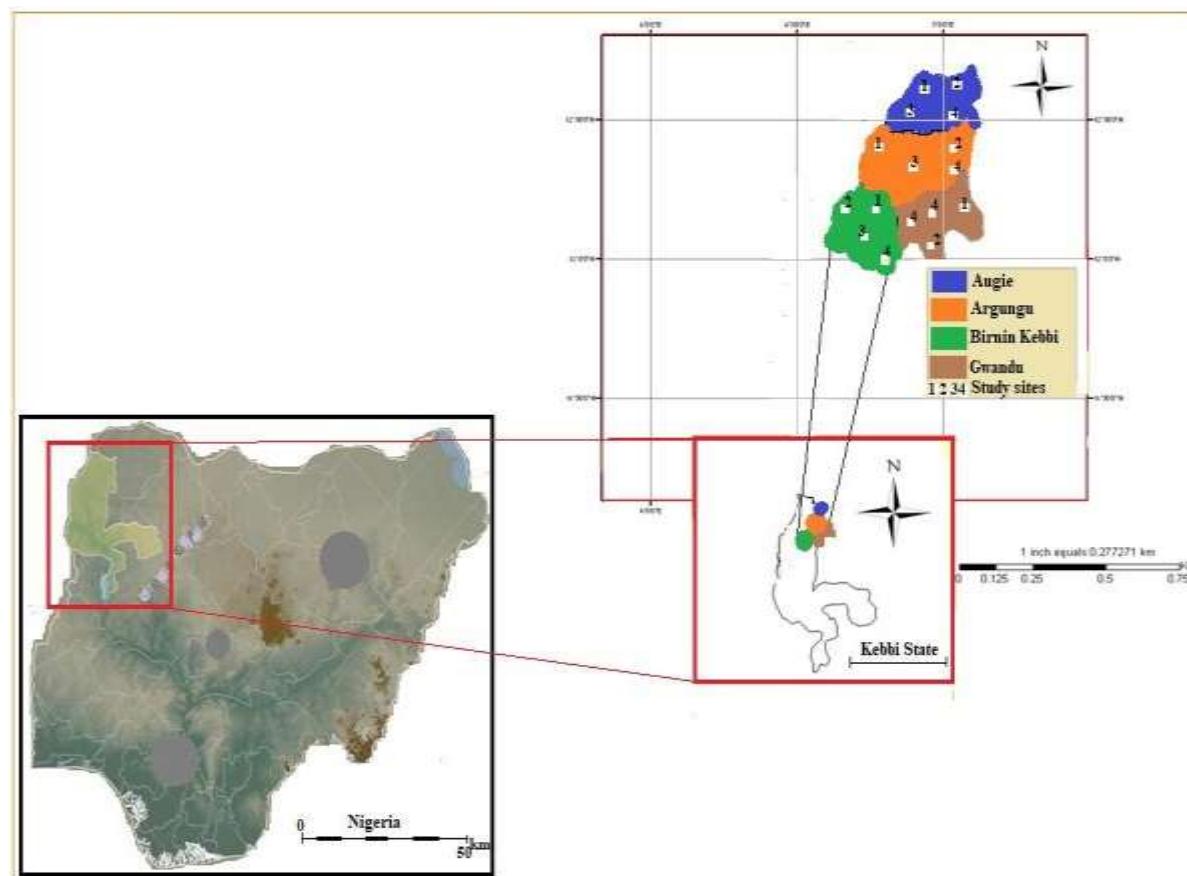


Figure 1: Map of study area and study sites

The zone has tropical weather conditions with three seasons: rainy, dry and hot (Usman et al., 2016). The annual rainfall is between 650 mm to 875 mm and monthly temperature ranged from 28°C to 42°C (Local Meteorological Record). The soil and surface soil conditions are characterized by presence of parent materials, which are largely of sand and clay particles originated from Sahara desert (Usman, 2007). The common agricultural land use practices include mono-cropping, mixed-cropping, inter-cropping and nomadic herding. The common crops grown are millet, sorghum, maize, rice, cowpea, groundnut, wheat and wide range of horticultural crops such as onions, pepper, tomatoes, and carrots among others.

Assessment of soil erosion based on physical impact

Gully erosion was assessed and classified in the field covering eighteen (18) different sites around Augie, Argungu, Birnin Kebbi and Gwandu (Figure 1). Field Book for Describing and Sampling Soils version 3.0 (Schoeneberger et al., 2021), was used to classify the nature and condition of gully erosion in the study sites. The Visual Soil Erosion Approach (VSEA) which comprised of soil quality (P-Sq) and land suitability (P-Ls) classes as introduced by Usman et al. (2024) was adapted for the evaluation of soil quality and land suitability for agricultural potentials. Similarly, soil structure, soil consistency, slope, and surface drainage classes, were assessed and evaluated according to the general classes described by Schoeneberger et al. (2021).

Soil sampling and laboratory analysis

Soil samples were collected using soil auger (0–20 cm depth) from all the 18 sites of the study area. At each site, four (4) different composite soil samples were collected; two of these samples were taken from the upper part of the gully section and the other two from the lower section. A total of seventy-two (72) different composite soil samples were collected for soil analysis in the laboratory. The analysis covered include; particle analysis for soil textural classes, analysis of organic matter, organic carbon, N, P, and K, pH, exchangeable Na, Mg, Ca and K. Particle analysis was determined using a Technico BS-604Bml C 20°C experimental cylinder that contains a scale of lines from 0 to 100%. The percentage sand, silt and clay were estimated based on guidelines in Schoeneberger et al. (2021) guideline for textural classification. Likewise, USDA-NRCS (Schoeneberger et al., 2021) criteria were used to define the soil texture for management application. Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter (FAO, 2022). Soil organic carbon (%) was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Total nitrogen (%) was determined by the Kjeldahl digestion and distillation procedure whereas available P and

K were determined according to Bray's No. 1 extracts (Bray and Kurtz, 1945). Exchangeable Magnesium (Mg^{2+} cmolkg⁻¹ soil), Sodium (Na^{2+} cmolkg⁻¹ soil), Calcium (Ca^{2+} cmolkg⁻¹ soil) and Potassium (K^{+} cmolkg⁻¹ soil) were determined using ammonium acetate (NH_4OAc) extract solution as described in Bray and Kurtz (1945).

Measurement of the gully erosion

Study on gully erosion was conducted based on the concept of direct measurement of soil erosion in the field (USDA, 2012). The assessment employed the use of ranging poles, measuring tape, computer system and digital imagery. Ranging poles were used to allocate the affected areas and also to identify points for measurement of the gully channel in the field. These ranging poles were placed in the soil at the surface, with intervals of 5 m between them across the gully length. Ten (10) poles were used at each site during the measurement exercise in the field. These ranging poles were used as a reference point for the overall measurement, and covered 10 different measurements transects or points at each of study site. Selection of these measurement points was base on random sampling within the affected area. At each point, depth (d), width at top (W_1), and width at bottom (W_2), were recorded by measuring the distance between the edge of the gully width and benchmark pins established around the gully width. These parameters were measured including the length (L), by placing the measuring tape to the edge of the gully over the exposed section on each point. The volume of soil loss was calculated as follows (USDA, 2012):

$$V = L \times \frac{(W_1 + W_2)}{2 \times d}$$

L was measured in the field from all the 3 sites as constant i.e. 12 m with an interval of 2 m extent from one point to another [2 m + 2 m + 2 m + 2 m + 2 m = 10 m] (see Figure 3).

Where: V = volume of soil loss

L = length

W_1 = the average top width measured from the gully channel and measured in the gully channel

W_2 = the average bottom width

d = the average depth of gully erosion

Statistical Analysis

All data were subjected to simple analysis using excel to compare the sum, average mean, minimum and maximum values of depth, width at top and width at bottom between the study sites.

3. RESULTS

Length, width, depth and volume of soil loss

The length, width (top and bottom), depth and volume of soil loss across the different sites are summarized in Table 1. The parameters reported were based on the measurement from the field assessment. The length described the distance end to end, and was considerably very high across the sites recorded around Birnin Kebbi (site 9 – 12) and Gwandu (site 13 – 16). Likewise, the distance across the gully channel and deepness, were found to be high in these sites compared to sites recorded around Augie (site 1 – 4) and Argungu (site 5 – 8). This could be the probable reasons for high soil loss recorded in the former sites compared to the lower volume recorded in the later sites. Of the 16 sites that were calculated as having a high volume of soil loss for gully erosion impact, more than half (13 sites) were actually measured as being critically damaged. The pattern for soil degradation and erosion impact predicted high risk of soil quality deterioration and possible landslides in future. The general trend was an increase of length, width and depth in the study sites for gully erosion and volume of soil loss, annually. Although, the combined factors, which could have contributed to both initial and existing trend of gully erosion across the study sites are unknown, however, the volume of soil loss reported (Table 1) revealed that the management application and vegetation are depressed as similarly noted by Usman et al. (2016).

Table 1: Length, width, depth and soil loss across the study sites

Site	Name of the study site	Length (m)	Width1 (m)	Width2 (m)	Depth (m)	Soil loss (m ³)
1	Kwararo	11.9	36.2	20.7	11.8	3983.6
2	Tungar Dangwari north	9.87	39.2	19.5	11.3	3263.1
3	Tungar Dangwari south	15.6	45.6	20.7	12.7	6544.3
4	Augie	11.9	18.2	9.10	5.71	241.60
5	Kewa	15.8	18.5	10.9	7.65	1776.8
6	Argungu 1	16.9	23.2	10.1	7.13	2010.4
7	Argungu 2	8.38	11.4	11.4	6.69	638.54
8	Helande	13.9	37.4	12.9	12.4	4332.2
9	Tarasa	138.3	99.5	32.7	15.5	14153.6
10	Badariyya	1005.8	130.7	108.5	8.67	142637.2
11	Kola	411.8	126.7	76.8	26.4	3171.5
12	Wuro Maliki	364.9	91.6	43.9	10.2	253178.3
13	Gwandu	378.9	88.8	43.8	31.7	796647.2
14	Lamude	452.6	61.5	17.2	13.3	236587.8
15	Garugga	271.6	106.0	50.4	23.9	507757.5
16	Tsohuwar Makaranta	251.5	44.7	17.9	11.9	93769.9

Comparison of width and depth

Table 2 to 3 provided a summarized data on width and depths in the study sites. The analysis compared the maximum, minimum, average ad standard deviation, and shows that the differences are apparent. This comparison was made individually for each study area (Table 2), and also across all the sites (Table 3). On average, site 10 recorded the highest width and site 4 has the lowest (Figure 2). On the other hand, site 13 has the highest depth whereas site 4 recorded the lowest (Table 3). These variations were also noted for the overall widths and depths across the study sites around Augie, Argungu, Birnin Kebbi and Gwandu (Figure 3, 4, 5 and 6). These could probably be related to the overall soil condition and vegetation cover across the study sites, which is more or less loose and poor (Table 4).

Table 2: Comparison of width and depth across the study sites

S/N	Site	W1m		W2m		Dm	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1.	/Dangwari north	5.91	2.29	3.11	1.52	1.58	0.73
2.	Kwararo	4.11	2.92	3.11	1.11	1.91	0.81
3.	/Dangwari south	6.13	2.81	2.4	1.05	1.77	0.58
4.	Augie	2.81	1.12	1.1	0.52	1.01	0.23
5.	Kewa	2.18	1.18	1.79	0.79	1.11	0.48
6.	Argungu 1	3.21	1.93	1.12	0.88	0.94	0.55
7.	Argungu 2	1.18	1.01	0.85	0.44	1.41	1.0
8.	Helande	5.63	2.34	1.83	0.91	1.81	0.73
9.	Tarasa	49.38	4.57	4.75	2.21	2.41	0.91
10.	Badariyya	22.56	7.44	21.64	0.01	8.666	0.08
11.	Kola	23.71	6.71	19.63	2.8	4.23	1.52
12.	Wuro Maliki	13.41	6.09	7.96	0.01	1.52	0.49
13.	Gwandu	12.5	3.78	43.83	1.68	4.79	1.68
14.	Lamude	8.9	2.74	2.47	1.15	2.04	0.88
15.	Garugga	14.63	7.34	7.62	3.05	3.98	1.85
16.	T/Makaranta	9.75	1.84	8.23	0.01	1.83	0.63

Table 3: Comparison of average width and depth across the study sites

S / N	Site	Average			STDV		
		W1	W2	d	W1	W2	d
	Tungar Dangwari north	3.919	2.136	1.127	1.318892	0.459376	0.277851
	Kwararo	3.623	2.07	1.171	0.456437	0.663643	0.385067
	Tungar Dangwari south	4.557	1.848	1.266	1.109705	0.678725	0.416232
	Augie	1.815	0.91	0.571	0.526165	0.157762	0.275013
	Kewa	1.845	1.093	0.846	0.351386	0.275118	0.429604
	Argungu 1	2.32	1.019	0.713	0.434792	0.086724	0.119912
	Argungu 2	1.139	0.669	1.143	0.048865	0.139718	0.134829
	Helande	3.505	1.315	1.242	1.086414	0.297405	0.382297
	Tarasa	9.953	3.27	1.548	13.87551	0.836687	0.552968
	Badariyya	13.07	10.853	0.8666	6.38206	7.281433	0.560317
	Kola	12.671	8.168	2.643	5.649176	5.813597	0.955743
	Wuro Maliki	9.164	4.398	1.023	2.268946	2.535161	0.345159
	Gwandu	8.879	4.383	3.17	2.820723	2.548577	8.658773
	Lamude	6.145	1.721	1.329	1.930908	0.389	0.498987
	Garugga	10.603	5.036	2.391	2.710927	1.439793	0.859709
	Tsohuwar Makaranta	4.474	1.788	1.191	2.212491	2.401323	0.33818

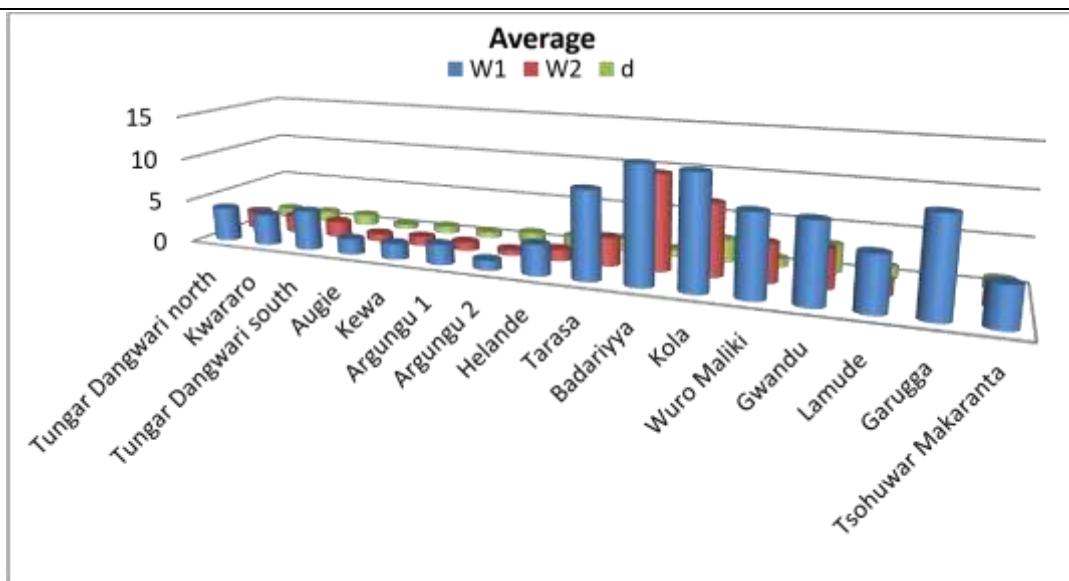


Figure 2: Average width across the study sites

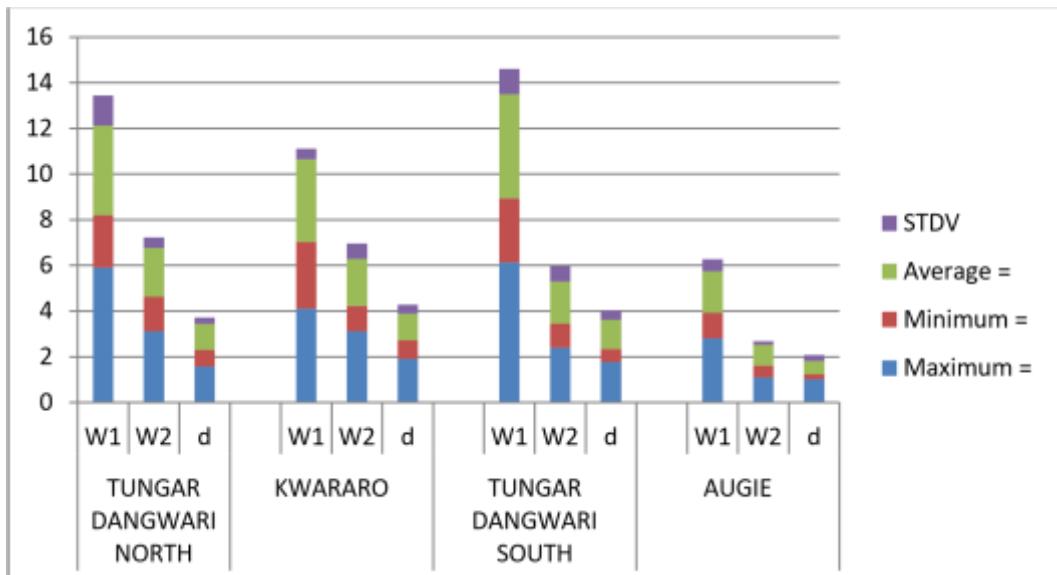


Figure 3: Gully erosion around Augie area Kebbi State

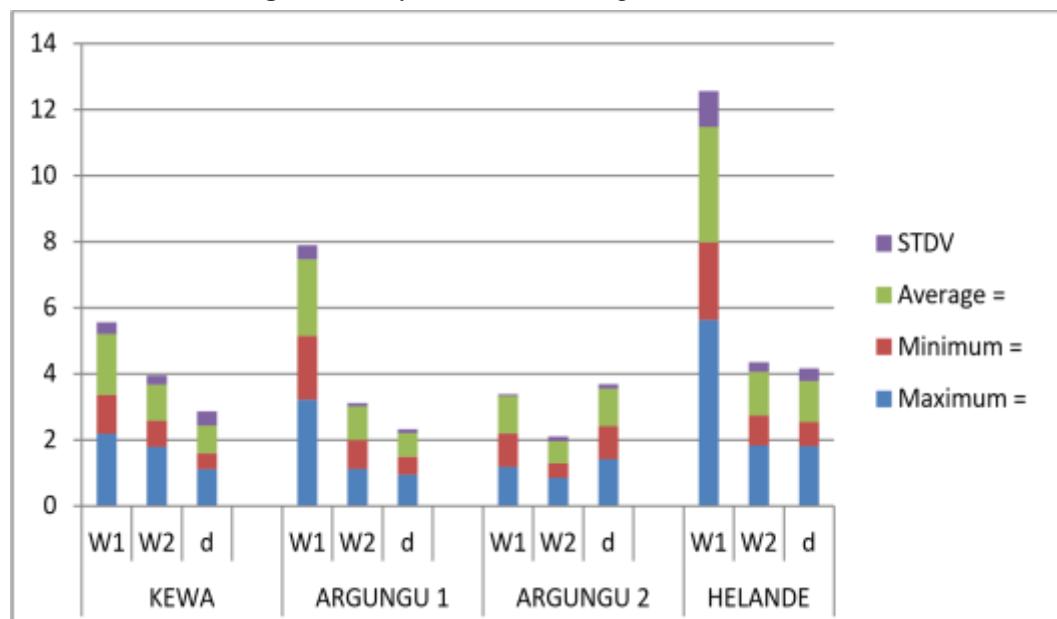


Figure 4: Gully erosion around Argungu area of Kebbi State

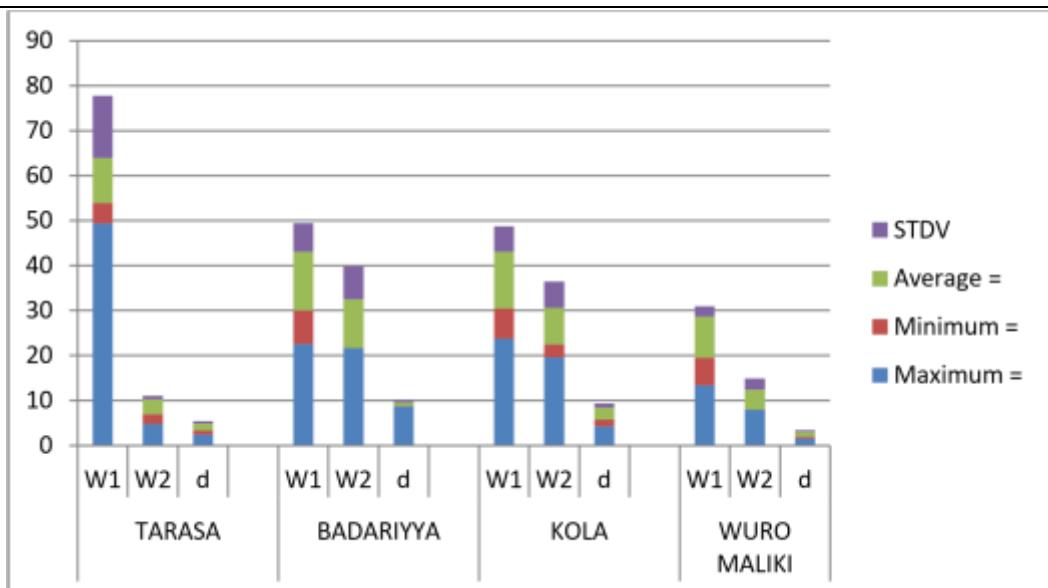


Figure 5: Gully erosion around Birnin Kebbi area of Kebbi State

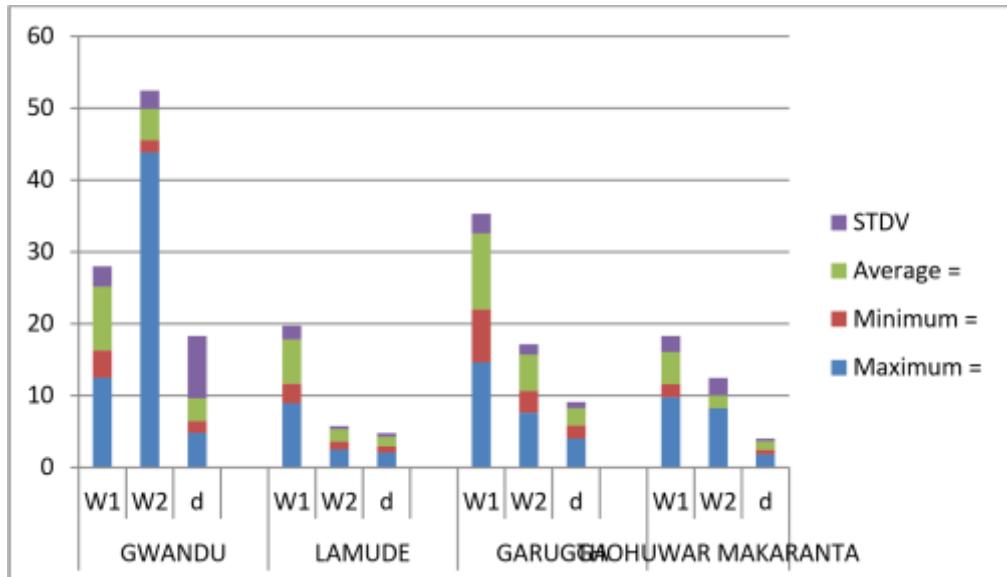


Figure 6: Gully erosion around Gwandu area of Kebbi State

Table 4: Soil loss, soil quality and land suitability classes in the study sites

Site Code	Study site	Soil loss (m ³)	Soil quality class (P-Sq)	Land suitability class (P-Ls)	Surface condition
1.	Kwararo	3983.6	Sq4	Ls4	Notably damaged
2.	T/Dangwari north	3263.1	Sq4	Ls4	Notably damaged
3.	T/Dangwari south	6544.3	Sq5	Ls5	Bad land
4.	Augie	241.60	Sq3	Ls3	Partly damaged
5.	Kewa	1776.8	Sq3	Ls3	Partly damaged
6.	Argungu1	2010.4	Sq4	Ls4	Notably damaged
7.	Argungu2	638.54	Sq3	Ls3	Partly damaged
8.	Helande	4332.2	Sq4	Ls4	Notably damaged
9.	Tarasa	14153.6	Sq5	Ls5	Bad land
10.	Badariyya	142637.2	Sq5	Ls5	Bad land
11.	Kola	3171.5	Sq4	Ls4	Notably damaged

12.	Wuro Maliki	253178.3	Sq5	Ls5	Bad land
13.	Gwandum	796647.2	Sq5	Ls5	Bad land
14.	Lamude	236587.8	Sq5	Ls5	Bad land
15.	Garugga	507757.5	Sq5	Ls5	Bad land
16.	Tsohuwar Makaranta	93769.9	Sq5	Ls5	Bad land

Table 4 shows the status of the surface soil condition in term of soil quality and land suitability for agricultural and soil management application. Compared with the volume of soil loss across the study sites, three major classes of soil quality and land suitability were identified (Table 4). Except for Sq3 and Ls3 which can be managed under rigorous soil conservation application, all other sites appeared to be in bad condition. Significant portion of lands on Sq5 and Ls5 has been lost physically the lands are very exposed to landslides and further surface soil damage which may occur in future. Management of the soil for future agriculture required a very extensive conservation application that could demand heavy equipment which could be highly costly.

Table 5: Soil structure and soil consistency of the study sites

Site Code	Study site	Structure type	Structure grade	Consistency wet	Consistency dry
1.	Kwararo	Single-grain	Weak	Soft	Very-friable
2.	T/Dangwari north	Single-grain	Structureless	Loose	Friable
3.	T/Dangwari south	Single-grain	Weak	Soft	Very-friable
4.	Augie	Single-grain	Weak	Soft	Very-friable
5.	Kewa	Granular	Moderate	Soft	Friable
6.	Argungu1	Single-grain	Weak	Loose	Very-friable
7.	Argungu2	Single-grain	Structureless	Loose	Very-friable
8.	Helande	Single-grain	Structureless	Slack	Loose
9.	Tarasa	Massive	Structureless	Slack	Loose
10.	Badariyya	Massive	Weak	Loose	Loose
11.	Kola	Massive	Weak	Loose	Loose
12.	Wuro Maliki	Granular	Moderate	Soft	Friable
13.	Gwandum	Granular	Moderate	Soft	Friable
14.	Lamude	Single-grain	Weak	Soft	Loose
15.	Garugga	Single-grain	Weak	Slack	Loose
16.	Tsohuwar Makaranta	Granular	Moderate	Soft	Friable

The sites' natural soil structural units known as pedogenic structure was described as granular, massive, and single-grain (Table 5). Sites characterized by granulated sorting appeared to have small polyhedrals and very irregular shapes, whereas sites dominated by massive arrangement naturally consist of soil particles, which are coherently mass with no structural units from the typical physical observation. Majority of the sites appeared to have single-grains arrangement that is non-coherent, loose and poorly coordinated (Table 5). Moderate soils in the study sites are well-formed, arranged from the typical observation in the field, whereas weak and structureless sites are fragile and poorly sorted. However, the degree and kind of cohesion and adhesion for these soils in the study sites were soft, loose, friable and very-friable at moist and dry condition (Table 5). This explained the nature and condition of the soil particles and how they were susceptible to erosion under a high rainfall intensity couple with poor vegetation cover across all the study sites many years ago.

Table 6: Slope and drainage characteristics of the study sites

Site Code	Study site	Slope complexity type	Slope shape	Drainage pattern	Drainage class
1.	Kwararo	Simple-complex	Linear-convex	Rectangular	Moderately

					Well-drained
2.	T/Dangwari north	Complex	Concave-convex	Parallel	Drained
3.	T/Dangwari south	Complex	Concave-concave	Radial	Excessively drained
4.	Augie	Levelled	Linear	Deranged	Well-drained
5.	Kewa	Levelled	Linear	Artificial	Drained
6.	Argungu1	Simple-complex	Linear-convex	Deranged	Excessively-drained
7.	Argungu2	Levelled	Linear	Annular	Moderately-well drained
8.	Helande	Simple	Linear	Deranged	Excessively-drained
9.	Tarasa	Complex	Convex-concave	Parallel	Drained
10.	Badariyya	Complex	Concave	Parallel	Moderately well-drained
11.	Kola	Simple-complex	Linear- concave	Rectangular	Well-drained
12.	Wuro Maliki	Complex	Convex	Rectangular	Drained
13.	Gwandu	Simple	Linear	Deranged	Well-drained
14.	Lamude	Complex	Convex- convex	Parallel	Well-drained
15.	Garugga	Simple	Linear	Deranged	Well-drained
16.	Tsohuwar Makaranta	Complex	Concave-convex	Karst	Excessively-drained

Table 6 describes the characteristics of the slope and nature of drainage across the study sites. Simple, complex and levelled, geographically conform very-well to surface geomorphology of the study sites. The basic drainage properties can be described as relative, although might have differed slightly due to nature of their surface geomorphic drainage patterns, which could be attributed to the typical slope complexity. Well-drained and excessively-drained sites experienced a rapid and very-rapid removal of water across the surface soil, leaving the soil particles loose and very loose (Table 6). These drainage conditions of study sites have caused many surface imbalances due to poor vegetation cover leading to expanding of gully erosion with different shapes and structures. Drained and moderately-well-drained soils experienced only wet condition in a very short time (typically within the root depth 0 – 20 cm) as observed around Argungu1, Tsohuwar Makabarta and Tarasa study sites. The soil textures in these two sites appeared to be the same and are closely related to soils of Wuro-Maliki, Gwandu, Badariya, Augie, Lamude and Kewa (Table 7). However, these sites differed from the soils of Garugga and T/Dangwari north which were described as loamy sand. Likewise, they differed from soils of Argungu2, Kwararo and Kola accordingly (Table 7). Soil bulk density was above 1 g/cm although diverge slightly across the sites probably due to the nature of particle size thickness, which also can be related to soil condition of the individual site (Table 4). Soil reaction was described by pH and appeared to be slightly acidic with the exception of Lamude which was found to be neutral, hence ideal for most crop production.

Table 7: Texture, Textural name, Bulk density (Bd), pH and EC

Site	Texture	%	Texture Name	Bd g/cm3	pH	EC ds/m
Argungu1	Clay	14	Sandy loam	1.65	6.65	0.07
	Silt	10				
Wuro Maliki	Clay	14	Sandy loam	1.7	6.8	0.06
	Silt	8				
	Sand	78				

Tarasa	Clay	18	Sandy loam	1.58	6.9	0.01
	Silt	6				
	Sand	76				
Gwandum	Clay	14	Sandy loam	1.58	6.9	0.01
	Silt	8				
	Sand	78				
Garugga	Clay	12	Loamy sand	1.52	6.7	0.05
	Silt	2				
	Sand	86				
Argungu2	Clay	22	Sandy clay loam	1.54	7	0
	Silt	6				
	Sand	72				
Badariyya	Clay	16	Sandy loam	1.57	6.5	0.06
	Silt	8				
	Sand	76				
Tsohuwar Makaranta	Clay	14	Sandy loam	1.5	6.5	0.07
	Silt	10				
	Sand	72				
Helande	Clay	8	Loamy sand	1.49	6.68	0.02
	Silt	6				
T/Dangwari north	Clay	12	Loamy sand	1.58	6.68	0.08
	Silt	2				
	Sand	86				
Kola	Clay	26	Sandy clay loam	1.7	6.9	0.01
	Silt	4				
	Sand	70				
Augie	Clay	12	Sandy loam	1.21	6.68	0.01
	Silt	8				
	Sand	80				
Kwararo	Clay	22	Sandy clay loam	1.5	6.97	0
	Silt	4				
T/Dangwari south	Clay	12		1.53	6.65	0.05
	Silt	8				
	Sand	70				
Kewa	Clay	12	Sandy loam	1.49	6.8	0.01
	Silt	18				
	Sand	70				
Lamude	Clay	16	Sandy loam	1.52	7.1	0.03
	Silt	8				
	Sand	76				

Table 8: Organic Carbon (%), Organic Matter (%), Nitrogen (%), Available Phosphorus (mg/kg) and Potassium, Exchangeable Bases (Cmol(+)/kg), Total Exchangeable Bases (Cmol(+)/kg), and Effective Cation Exchange Capacity (Cmol(+)/kg)

	OC	OM	N	P	Na	K	Ca	Mg	Al+H	TEB	ECEC
Argungu 1											
1	0.2	0.3	0.0093	3.4	0.16	0.081	0.65	0.31	0.59	1.201	1.79
2	0.1	0.2	0.0095	3.1	0.18	0.093	0.58	0.32	0.61	1.089	1.69
3	0.2	0.4	0.0097	3.1	0.16	0.067	0.66	0.29	0.63	1.177	1.81
4	0.3	0.3	0.0091	3.3	0.14	0.074	0.65	0.25	0.66	1.114	1.77
Wuro Maliki											
1	0.8	1.37	0.00528	1.37	0.31	0.12	0.7	0.2	0.5	1.33	1.83
2	1.4	2.4	0.00258	2.4	0.23	0.099	1.9	0.44	0.73	2.669	3.39
3	0.2	0.3	0.0068	0.3	0.16	0.083	.59	0.30	0.59	1.133	1.72
4	0.8	1.37	0.00528	1.37	0.31	0.11	0.7	0.2	0.5	1.23	1.73
Tarasa											
1	0.76	1.31	0.00227	1.31	0.14	0.071	0.7	1.9	0.66	3.81	4.47
2	0.264	0.41	0.00212	0.44	0.32	0.082	0.05	1.85	1.16	2.3	3.45
3	0.42	0.724	0.00249	0.724	0.34	0.15	1.2	0.2	0.61	1.89	2.55
4	0.75	1.33	0.00326	1.33	0.13	0.051	0.9	1.8	0.57	2.88	3.45
Gwandu									0.66		
1	0.2	0.34	0.00144	0.34	0.17	0.082	0.05	1.05	0.66	1.35	2.01
2	1	1.72	0.014	1.72	0.37	0.095	1.65	1.65	0.69	2.665	3.32
3	1	1.72	0.0014	1.72	0.33	0.088	1.58	1.58	0.56	2.608	3.29
4	0.2	0.34	0.00144	0.34	0.17	0.082	1.05	1.05		1.35	1.91
Badariyya											
1	0.32	0.55	0.00315	0.55	0.21	0.11	0.5	0.5	0.5	2.72	3.22
2	0.9	1.55	0.00239	1.55	0.34	0.08	1.15	1.15	0.83	2.72	3.55
3	0.32	0.55	0.00315	0.55	0.21	0.11	0.5	1.9	0.5	2.72	3.22
4	0.8	1.65	0.00333	1.65	0.29	0.07	1.19	1.15	0.77	2.70	3.47
Garugga											
1	0.42	0.724	0.00249	0.724	0.34	0.15	0.2	0.2	0.61	1.89	2.55
2	0.99	1.32	0.00315	1.32	0.32	0.3	0.05	0.05	0.66	1.65	2.31
3	1.08	1.77	0.00072	1.77	0.29	0.064	0.3	0.3	0.56	1.56	2.12
4	0.06	0.1	0.00204	0.1	0.1	0.086	0.4	0.4	0.56	1.246	1.81
Helande											
1	0.58	1	0.008	3.89	0.37	0.1	1.1	0.5	0.33	2.07	2.40
2	0.32	0.55	0.00315	3.89	0.21	0.11	1.9	0.5	0.5	2.72	3.22
3	1.4	2.4	0.00258	2.1	0.23	0.099	1.9	0.55	0.83	2.779	3.61
4	0.42	0.724	0.00249	4.04	0.35	0.16	1.2	0.2	0.66	1.91	2.57
Tsohuwar Makaranta											

1	1	1.72	0.0014	3.5	0.37	0.095	0.55	1.65	0.66	2.665	3.33
2	0.42	0.724	0.00249	4.04	0.35	0.16	1.2	0.2	0.66	1.91	2.57
3	1	1.72	0.0014	3.5	0.37	0.095	0.55	4.65	0.66	2.665	3.33
4	1	1.72	0.0014	3.5	0.33	0.088	0.61	1.58	0.69	2.608	3.29
T/Dangwari South											
1	0.6	1.03	0.00154	2.93	0.34	0.02	1.3	0.2	0.66	1.86	2.52
2	0.1	0.2	0.0095	3.1	0.18	0.093	0.58	0.32	0.61	1.089	1.69
3	0.2	0.4	0.0097	3.1	0.16	0.067	0.66	0.29	0.63	1.177	1.81
4	0.6	1.01	0.00134	2.73	0.24	0.02	1.3	0.2	0.63	1.76	2.49
Kola											
1	0.42	0.724	0.00249	4.04	0.35	0.16	1.2	0.2	0.66	1.91	2.57
2	0.6	1.03	0.0154	2.93	0.34	0.02	1.3	0.2	0.66	1.86	2.52
3	0.86	1.48	0.00311	2.57	0.29	0.1	0.8	0.5	0.66	1.69	2.35
4	0.4	0.68	0.0096	3.9	0.2	0.11	1.7	0.25	0.5	2.21	2.71
Augie											
1	0.9	1.55	0.00239	18.8	0.34	0.8	1.15	1.15	0.83	2.72	3.55
2	0.4	0.68	0.0096	3.9	0.2	0.11	1.7	0.25	0.5	2.21	2.71
3	0.9	1.55	0.00239	18.8	0.34	0.8	1.15	1.15	0.83	2.72	3.55
4	0.6	1.3	0.00154	2.93	0.34	0.02	1.3	0.2	0.61	1.86	2.49
Kwararo											
1	0.24	0.41	0.00212	4.54	0.32	0.082	0.05	1.85	1.16	2.3	3.45
2	1.34	2.31	0.00247	2.3	0.32	0.13	0.05	0.1	0.66	0.6	1.26
3	1.08	1.86	0.00072	4.1	0.34	0.086	1.25	0.5	0.66	2.17	2.83
4	0.3	0.3	0.0091	3.3	0.14	0.074	0.65	0.25	0.66	1.114	1.77
T/Dangwari South											
1	1.34	2.31	0.00247	2.3	0.32	0.13	0.05	0.1	0.66	0.6	1.26
2	1.08	1.86	0.00072	4.1	0.34	0.086	1.25	0.5	0.66	2.17	2.83
3	0.24	0.41	0.00212	1.54	0.32	0.082	0.05	1.85	1.16	2.3	3.45
4	0.42	0.724	0.00249	4.04	0.34	0.15	1.2	0.2	0.61	1.89	2.55
Kewa											
1	0.86	1.48	0.00311	2.57	0.29	0.41	0.8	0.5	0.66	1.69	2.35
2	0.88	1.51	0.00311	2.51	0.31	0.2	0.7	0.5	0.61	1.71	2.32
3	0.79	1.46	0.00301	2.54	0.28	0.1	0.8	0.6	0.59	1.78	2.37
4	0.90	1.48	0.00311	2.61	0.26	0.1	0.9	0.4	0.68	1.66	2.34
Lamude											
1	1.8	1.77	0.00072	4.2	0.29	0.064	0.91	0.3	1.56	1.56	2.12
2	1.08	1.75	0.00062	4.1	0.39	0.071	0.87	0.4	1.7	1.71	2.2.
3	0.86	1.48	0.00311	2.57	0.29	0.1	0.8	0.5	1.69	1.69	2.35
4	1.08	1.86	0.00081	4.2	0.33	0.044	0.9	0.6	0.66	1.87	2.53

Table 8 above presented a set of chemical data that described the fertility status of the study sites. Percentage OC, OM and N appeared to be between low and very low across the study sites. Exchangeable bases were recorded to have shown different abilities to attract important compound for soil quality and soil fertility development. Sites such as Badariya, Kola, Augie, Helande Kewa and Lamude recorded the highest TEB and ECEC. These sites probably seem to benefit from soil management and conservation application compared to those of other study sites.

4. DISCUSSION

Surface soil is a shield layer that protects soils against soil erosion and runoff (Usman et al., 2017)

Soil erosion was found to have affected this surface shield layer across the study sites (Table 1–5). The impact was noted to have caused serious damage to soil quality and soil fertility, and affected the overall physical, biological and chemical components of soil resources, biological life and biodiversity (Al-Shoumik et al., 2023). The results from this study shows that some sites were severely damaged due to nature and condition of the gullies, which described the land as bad and damaged (Table 4). This is in agreement with other studies, which described the physical and quantitative impact of soil erosion as nuisance to agricultural soils in Africa (Usman et al., 2017; Onyelowie, et al., 2018; Ezeh et al., 2024). The volume of soil loss across the study sites was noted to have affected the soil quality (Sq) land suitability (Ls) potentials for agricultural production in the study sites (Table 4). Although, this could be probably due to the nature of soil particles and drainage characteristics as described in Table 5 and 6, however, the overall land quality was believed to be at a very high risk of degradation (Evans, 2013) because significant part of the land has already been destroyed (Table 1 – 3). This could lead to a serious deterioration to biological organisms and major components of soil physical, biological and chemical properties across the study sites (Al-Shoumik et al., 2023). Soil detachment across the study sites during the rainy season is likely to increase annually because of the damage that had caused significant deterioration of the soil particles (Gebrie et al., 2023). This will increasingly affect the potential of soil to support plant production for improved food security (Andualem et al., 2023). Therefore, an increased of width, depth and length of gully erosion in the study sites is likely to cause more frequent landslides and advanced soil loss in the study area (Andualem et al., 2023; Baade et al., 2024). The consequence of this incident could lead to total decline in the overall soil quality and soil fertility status across the study sites (Usman et al., 2024a). This was further explained from the overall chemical data reported in Table 8. Generally, soil erosion was considered one of the environmental factors deteriorating soil nutrient content, and may lead to decreased in soil fertility and food security (Valkanou et al., 2022; Baade et al., 2024; Wen et al., 2024).

The physical damage caused by the expanding width and depth of gully erosion from end to end parts of the affected area is an indication of poor soil quality and land productivity (Figure 3 – 5). This is a global threat to sustainable soils and food security (Li et al., 2024). It is also a serious environmental hazard to sustainable economic growth in Africa (Salhi et al., 2023). However, the significance of this impact in the study sites is believed to have been increased due to natural conditions of the drainage characteristics, which are also subject of consideration across the study sites (Table 2). Soil conditions with the drainage patterns reported in this study was considered vulnerable to soil erosion assault, and could lead to significant surface soil damage (Usman, 2024). Particle size characteristics revealed that soil texture was dominated by sand particles (Table 7). Obviously, the sites characterized by dominant sand particles could be the reason for its high rate of erosion and could also lead to unexpected landslides in the future (Baade et al., 2024). The result shows that the impact of gully erosion is advancing, and can be quantified from the amount of soil loss from the various depths and widths recorded across the study sites (Table 2 – 5). Perhaps, this could be responsible for destroying the productive potential of soil and its major soil functional services, such as nutrient cycle (Usman et al., 2016; Usman et al., 2019). This shows importance of taking immediate action for the sustainable soil management and conservation of the affected sites, and is also equally useful for soil and water management in the region (Usman, 2024a; Usman, 2024c). However, one of the recent aspects of this management with regards to erosion impact is the use of technological and agronomic management options, which involved multiple scientific and traditional approaches (Srinivasarao et al., 2023; Usman, 2024b; Usman, 2024c).

5. CONCLUSION

This study has shown that the surface soil conditions of the study area were seriously affected by gully erosion across the study sites. The assessment observed that gully erosion has caused surface soil damage and has also caused threat to soil productivity. The volume of soil loss was described by the typical width and depth and provided a clear depiction of the physical and quantitative impact of gully erosion in the study sites. The study clearly highlighted the occurrence of gully erosion threatening agricultural lands and soil resources in the study sites. Gully erosion is expanding and the cost of management is also likely to increase on annual basis because of the increasing size of widths and depths across the study areas. Soil condition in terms of soil quality and fertility status appeared to have been affected, and the impact

are physical, biological and chemical. This study demonstrated cleared evidence of the potential decrease of agricultural land and crop production in the study sites. This study suggests the need for appropriate conservation applications involving both the technical and traditionally based approaches. These sustainable conservation applications may include; planting of shelter belt across the affected sites, advanced drainage systems and provision of water ways, inter- and mixed cropping systems. Farmers need to be equipped technically with skills on how to manage their land sustainably to avoid degradation and improve their livelihood.

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