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Measurement of width, depth and soil loss for gully erosion impact in the Sudan Savannah region, Kebbi State Nigeria

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Abstract

Soil erosion has become global news as it affects soil, environmental and food security in many nations. Gully erosion is one of the serious types of soil erosion that damages soil productivity and soil quality in African drylands. The aim of this study was to measure the impact of gully erosion based on width, depth and soil volume loss in the Sudan Savannah's dryland of Kebbi State Nigeria. Gully erosion impact was recorded and calculated based on USDA standard method of measuring soil erosion in the field. Results show that the highest 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 Argungu2. Likewise, maximum depth (8.666 m) was recorded at Badariyya and minimum (0.94 m) was recorded at Argungu. The soil physical properties revealed that soil structural configuration were classified as granular, massive and single-grains, and are non-coherent but loose and poorly sorted. Most of the sites have more that 65% sand characterized as low organic matter, nitrogen and CEC. Sites were considerably affected by gully erosion and the impact was physical and quantitative. Soil quality (Sq) and land suitability (Ls) potentials for agricultural production were affected. The affected sites were evaluated as bad land (Sq5, Ls5), notably damaged (Sq4, Ls4) and partially damaged (Sq3, Ls3). The study recommended the use of advanced soil conservation measures across the affected sites, which will employ the adaptation of water harvesting systems, orchard plantation and drainages.

Key words: gully erosion, width of gully, depth of gully, soil volume loss, physical properties, chemical properties

Introduction

Soil erosion is a threat to dryland soils, and global sustainable use of agricultural and non-agricultural soils (Rui et al., 2024). Soil erosion is a serious environmental problem in African drylands, and has affected soil quality and land suitability in the region (Usman, 2025). In the Sudan Savannah zone of Kebbi State dryland, soil erosion was considered threat to soil and food security because of its environmental and economic impact across the State (Usman et al., 2025). Soil erosion impact was regarded as removal of soil particles, deterioration of soil properties and damaging the potential productivity of soil to support plants and ensure food security (Andualem et al., 2023). Soil erosion is regarded as one of the major global soil challenges that have created many imbalances to global soil health, soil quality and soil productivity (Andualem et al., 2023). It affects the surface and subsurface soil components and soil functional services to support production and ensure sustainable economy (Gezici et al., 2025). Soil erosion leads to decreases ecosystem functions leading to landslides, flooding, loss of vegetation cover, decrease biodiversity and damages rural-urban infrastructures (FAO, 2023). Indeed, soil erosion is a hazard to the global ecological ecosystems, which include natural vegetation, agricultural soils, lands, water bodies, forest resources and human and environmental health (Dou et al., 2022). According to Global Soil Partnership report of 2017, approximately 75 billion tons of global soils are eroded from arable lands annually, and was estimated to have cost US$400 billion per year (FAO-GSP, 2017). This impact of soil erosion was noted to have affected approximately 2.6 to 3.2 billion people globally (Singh et al., 2023). This soil erosion impact has now become a concern threat to global population and economy more especially in sub-Saharan Africa (Usman et al., 2017). Therefore, it had created a further serious concern to overall soil physical, biological and chemical components of agricultural lands (Al Shoumik et al., 2023). Generally, soil erosion has caused surface soil damage; decrease the size of land potential for agriculture and economic growth of the growing population in sub-Saharan Africa (Ezeh et al., 2024).

The physics of soil erosion was noted to have forced the surface soil particles to detach, damages soil structural quality and creates gully channels (Andualem et al., 2023). This process of detachment, moved soil particles and surface soil materials from one area to another creating different forms of sheets, rills and gullies (Usman et al., 2019; Andualem et al., 2023). In Sudan Savannah zone of Kebbi State, this movement of soil particles by erosion, was reported to have caused surface soil damage and formed the sheets (top surface soil layer deterioration), rills (smaller channels), and gullies (larger channels) (Usman et al., 2025). The initial rate of this process of removal of surface soil materials was looked as a form of depression by rainfall impact (splash erosion) which can be extended to sheet, rill and gully erosion (Baade et al., 2024). Usman, (2025) described the images of how concentrated these types of erosion are, as a serious environmental concern that need to be assess from time to time. This is because the occurrence of each of the individual type of soil erosion depends largely on the nature and condition of the soil properties, slope, vegetation cover of and land use activities (Usman and Jayeoba, 2024). And, in Sudan Savannah of Kebbi State, the surface soil sites subjected to continuous cultivation without proper soil management, lack of tree plantation and mismanagement of vegetation shrubs and plants, are considered very prompt to soil erosion (Usman, 2016). According to Evans, (2013), these surface soil sites are likely to always wash away easily by rains as they experienced poor vegetation cover and poor management practices.

According to Pandey et al. (2016), the process of soil erosion was understood to have caused by combination of natural environmental factors, which include rainfall variability, wind, waves and bioturbation including human-induced factors such as over-ploughing, overgrazing, building, deforestation, forest fires and off road vehicles. However, in the Sudan Savannah zone of Kebbi State, the combined factors appeared to have observably caused many developments in the occurrence of gully erosion around Augie, Argungu, Birnin Kebbi and Gwandu areas (Usman et al., 2016). Climate change impact as a serious threat to surface soil condition under poor vegetation cover was also believed to have increased the incident of gully erosion occurrence in the Sudan Savannah zones of Africa (Usman et al., 2024). The expanding of gullies increases the cost of erosion control and reduces the overall environmental qualities (Yang et al., 2023). Poverty and hunger, environmental contaminations and declined soil productivity and food security, are also associated to soil erosion impact in the Sudan Savannah zone of Kebbi State (Usman et al., 2016). This could also lead to rural-urban migration, increase hunger, malnutrition and environmental scarcity in the region (Usman, 2013). Detail soil survey studies in the region have placed a call for regular assessment of soil erosion across the affected sites (Usman et al., 2020). This will help provide soil data required for the adaptation of appropriate soil conservation in the affected areas of the State (Jat et al., 2023). Therefore, this study was aimed to measure the width, depth, length and soil volume loss around Augie, Argungu, Birnin Kebbi and Gwandu local government areas of Kebbi State Nigeria.

Materials and methods

Area of study

Kebbi State is geographically located in northwest Nigeria and dominated by Hausa-Fulani who have largely depended on farming and rearing animals. The State has a total land area of 36,229 km^2 of which 12,600 km^2 that 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 governments' 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 (fig. 1).

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. The soil and surface soil condition are characterized by presence of parent materials, which are largely of sand and clay particles originated from Saharan desert (Usman, 2007). The common agricultural land use practices include mono-cropping, mixed-cropping, inter-cropping and cattle rearing. 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.

Methods used for gully erosion impact assessment

Gully erosion was assed and classified in the field covering sixteen (16) different sites around Augie, Argungu, Birnin Kebbi and Gwandu (fig. 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 analysis

Soil samples were collected using soil auger (0-20 cm depth) from all the 16 sites of the study area. At each site, a composite soil sample was taken from upper and lower part of the gully affected site. A total of 16 different composite soil samples were packed for soil analysis in the lab. The analysis covered the 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

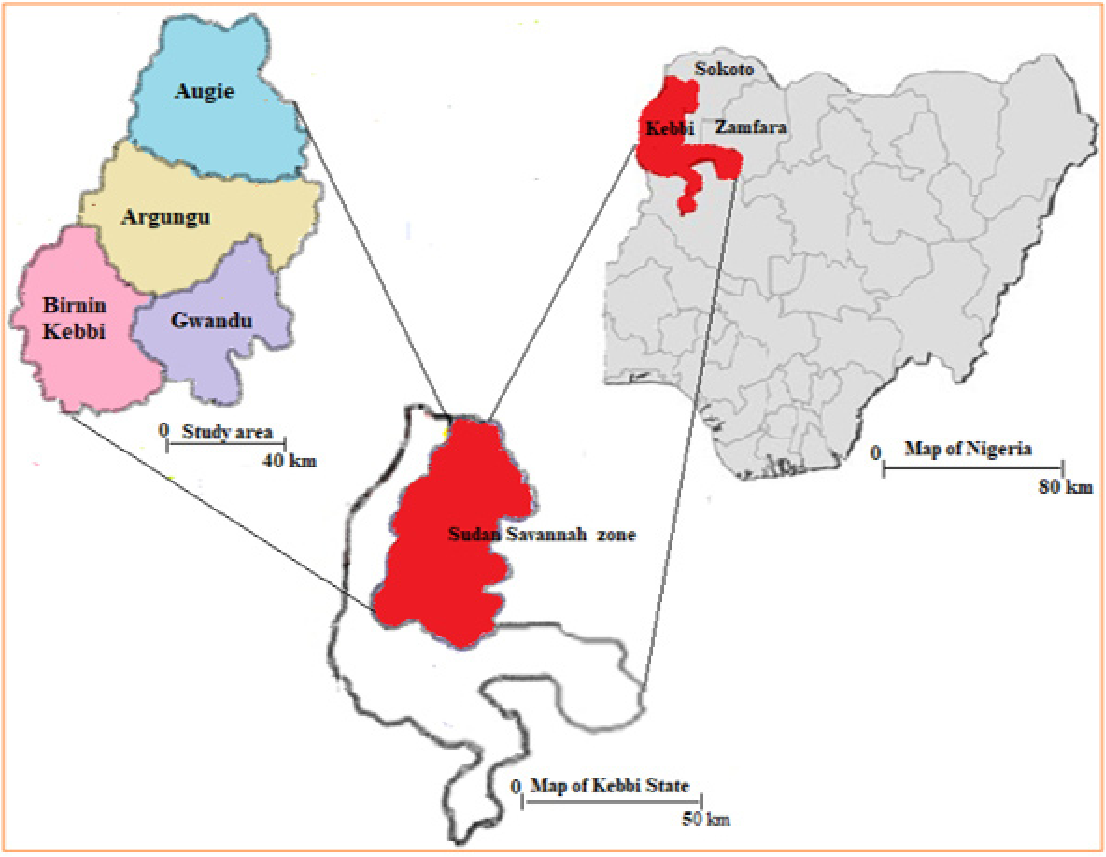

Fig. 1. Map of Kebbi State Nigeria area and study area

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).

Gully erosion assessment

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 range poles, measuring tape, computer system and digital imagery. Range poles were used to allocate the affected areas and also to identify point-by-point for measurement of the gully channel in the field. These range poles were placed-in into 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 range poles were used as a reference point of the overall measurement, and covered 10 different measurements transects or points at each of study site. Selection of these measurement points was based on random sampling within the affected area. At each point, depth (d), width at top (W1), and width at bottom (W2), 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):

$$V = L\,x\,\frac{(W1 + W2)}{2\,x\,d}$$

Where: V = volume of soil loss
L = length
W1 = the average top width measured from the gully channel
W2 = the average bottom width measured in the gully channel
d = the average depth of gully erosion

Statistical Analysis

All data was 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.

Results

Length, width, and depth of gully erosion 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 are 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, then 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).

Comparison of width and depth of gully erosion across the study sites

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 (fig. 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 (fig. 3). These could be probably related to the overall soil condition and vegetation cover across the study sites, which is more or less loose and poor (table 4).

Table 4 shows the status of the surface soil condition in term of soil quality and land suitability for agricultural and 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 the other sites appeared to be in bad condition.

Table 1. Length, width and depth of a gully erosion 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 Dang-wari north	9.87	39.2	19.5	11.3	3263.1
3	Tungar Dang-wari 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	16.9	23.2	10.1	7.13	2010.4
7	Argungu	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	Badariya	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

Table 2. Comparison of width and depth of a gully erosion (W1 top width, W2 bottom width, D depth)

Site		W1 m		W2 m		D m	
		Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1	T/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	T/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 of a gully erosion (W1 top width, W2 bottom width, D depth)

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

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

S/N	Study site	Soil loss (m^3)	Soil quality class (P-Sq)	Land suitability class (P-Ls)	Label of the surface condition
1	Kwararo	3983.6	Sq4	Ls4	Notably damaged
2	T/Dangwari1	3263.1	Sq4	Ls4	Notably damaged
3	T/Dangwari2	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	Badariya	142637.2	Sq5	Ls5	Bad land
11	Kola	3171.5	Sq4	Ls4	Notably damaged
12	Wuro Maliki	253178.3	Sq5	Ls5	Bad land
13	Gwandu	796647.2	Sq5	Ls5	Bad land
14	Lamude	236587.8	Sq5	Ls5	Bad land
15	Garugga	507757.5	Sq5	Ls5	Bad land
16	T/Makaranta	93769.9	Sq5	Ls5	Bad land

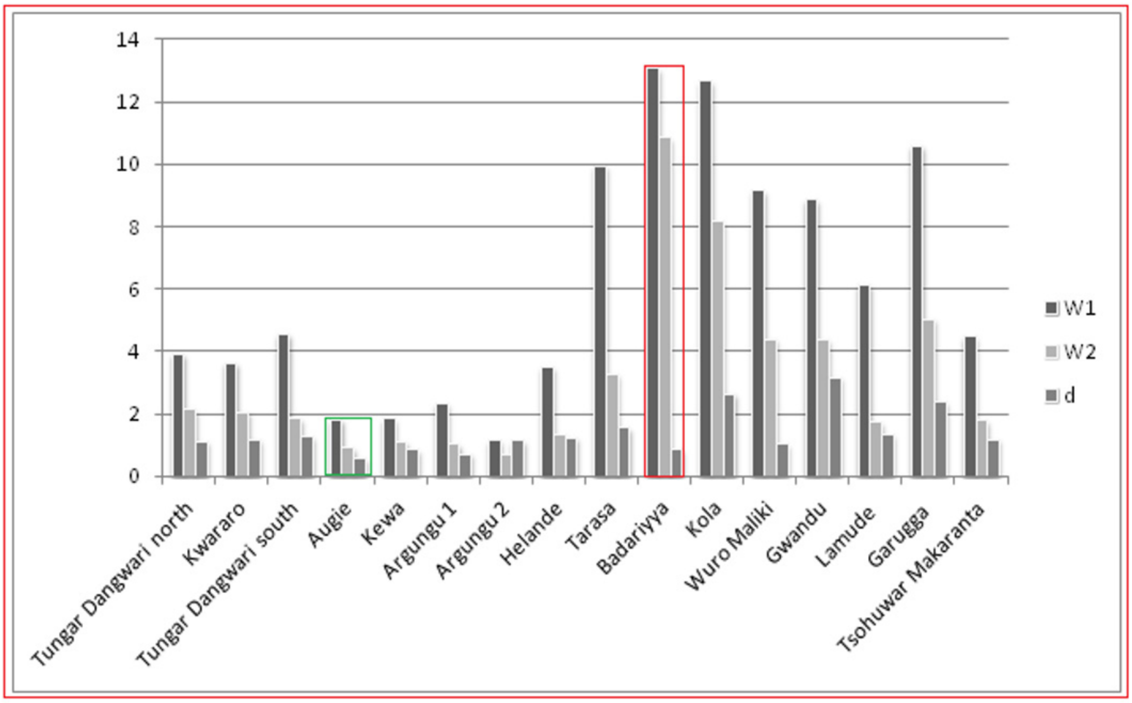

Fig. 2. Average width and depth of gully erosion across the study sites (W1 top width, W2 bottom width, D depth)

Significant portion of lands on Sq5 and Ls5 has been lost and physically the lands are very exposed landslides and further surface soil damage which may probably take into account in future. Management of the soil for future agriculture required a very extensive conservation application that could demand heavy equipment.

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 are naturally consist of soil particles, which are coherently mass with no structural units from the typical observation in hand. 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 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 describes the characteristics of the slope and nature of drainage across the study sites. Simples, complex and leveled are 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 viewed to be of typical slope complexity. Well-drained and excessively-drained sites experienced a rapid and very-rapid removal of water across the surface soil living 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 struc-

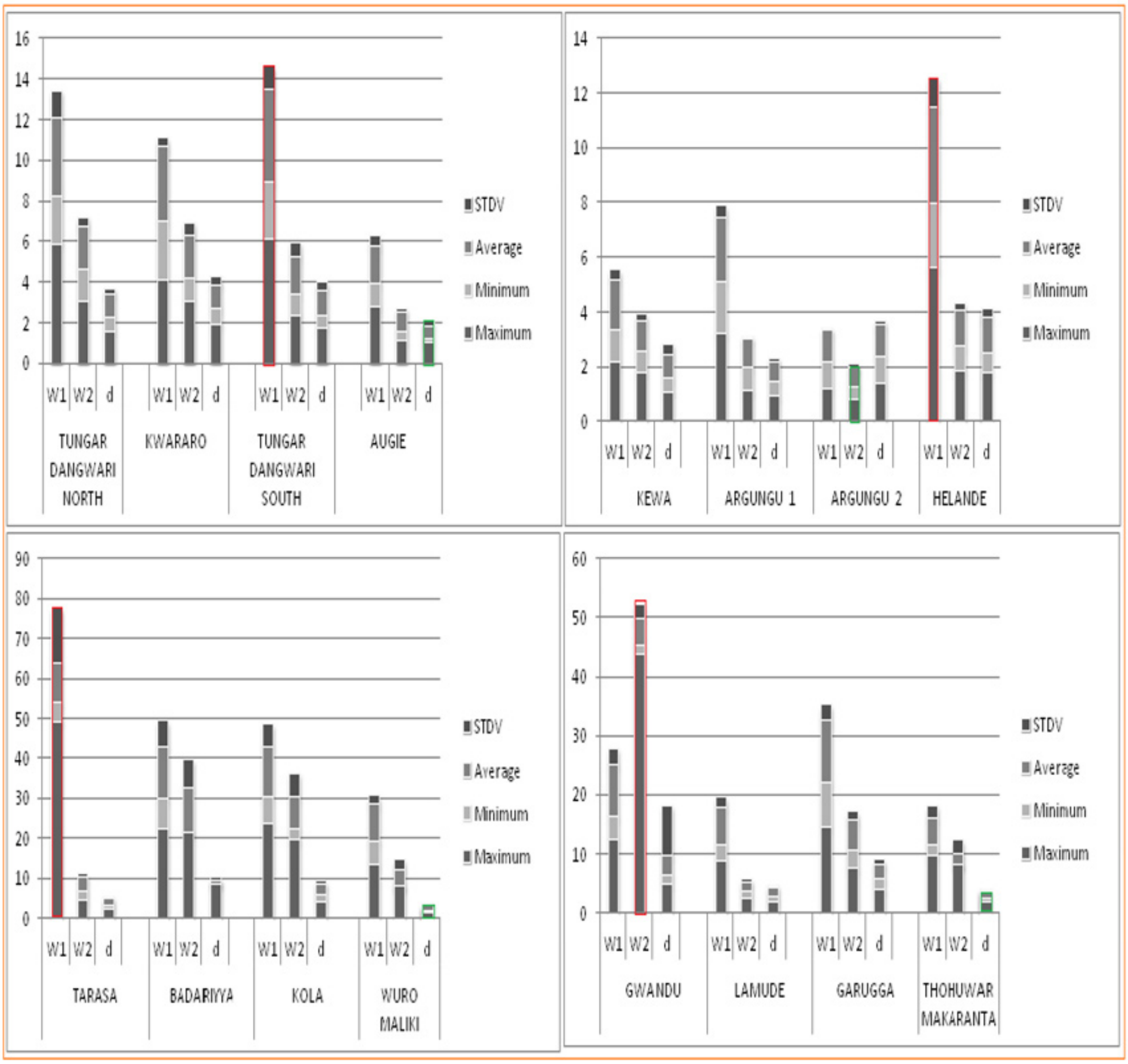

Fig. 3. Gully erosion (cm) across the study sites (W1 top width, W2 bottom width, D depth)

tures. 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 Makaranta and Tarasa study sites. The soil textures in these two sites appeared to be the same and are closely related soils of Wuro-Maliki, Gwandu, Badariyya, 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 recoded to be normal for crop production.

Table 8 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 indicated different abilities to attract important compound for soil quality and soil fertility development. Sites such as Badariyya, Kola, Augie, Helande Kewa and

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

S/N	Study site	Structure type	Structure grade	Consistency wet	Consistency dry
1	Kwararo	Single-grain	Weak	Soft	Very-friable
2	T/Dangwari1	Single-grain	Structureless	Loose	Friable
3	T/Dangwari2	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	Badariya	Massive	Weak	Loose	Loose
11	Kola	Massive	Weak	Loose	Loose
12	Wuro Maliki	Granular	Moderate	Soft	Friable
13	Gwandu	Granular	Moderate	Soft	Friable
14	Lamude	Single-grain	Weak	Soft	Loose
15	Garugga	Single-grain	Weak	Slack	Loose
16	T/Makaranta	Granular	Moderate	Soft	Friable

Table 6. Slope and drainage characteristics of the study sites

S/N	Study site	Slope Complexity	Slope shape	Drainage pattern	Drainage class
1	Kwararo	Simple-complex	Linear-convex	Rectangular	Moderate-drained
2	T/Dangwari1	Complex	Concave-convex	Parallel	Drained
3	T/Dangwari2	Complex	Concave-concave	Radial	Excessive-drained
4	Augie	Leveled	Linear	Deranged	Well-drained
5	Kewa	Leveled	Linear	Artificial	Drained
6	Argungu1	Simple-complex	Linear-convex	Deranged	Excessive-drained
7	Argungu2	Leveled	Linear	Annular	Moderate-drained
8	Helande	Simple	Linear	Deranged	Excessive-drained
9	Tarasa	Complex	Convex-concave	Parallel	Drained
10	Badariya	Complex	Concave	Parallel	Moderate-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	T/Makaranta	Complex	Concave-convex	Karst	Excessive-drained

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

Study site	Texture			Texture name	Bd g/cm^3	pH	EC ds/m
	Clay	Silt	Sand				
Argungu1	14	10	66	Sandy loam	1.65	6.65	0.07
Wuro Maliki	14	8	78	Sandy loam	1.7	6.8	0.06
Tarasa	18	6	76	Sandy loam	1.58	6.9	0.01
Gwandu	14	8	78	Sandy loam	1.58	6.9	0.01
Garugga	12	2	86	Loamy sand	1.52	6.7	0.05
Argungu2	22	6	72	Sandy clay loam	1.54	7	0
Badariyya	16	8	76	Sandy loam	1.57	6.5	0.06
T/Makaranta	14	10	72	Sandy loam	1.5	6.5	0.07
Helande	8	6	12	Loamy sand	1.49	6.68	0.02
T/Dangwari1	12	2	86	Loamy sand	1.58	6.68	0.08
Kola	12	4	70	Sandy clay loam	1.7	6.9	0.01
Augie	12	8	80	Sandy loam	1.21	6.68	0.01
Kwararo	22	4	74	Sandy clay loam	1.5	6.97	0
T/Dangwari2	12	7	71	Sandy loam	1.53	6.65	0.05
Kewa	12	8	70	Sandy loam	1.49	6.8	0.01
Lamude	16	8	76	Sandy loam	1.52	7.1	0.03

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)

Study site	OC	OM	N	P	Na	K	Ca	Mg	Al+H	TEB	ECEC
Argungu1	0.2	0.3	0.0093	3.4	0.16	0.081	0.65	0.31	0.59	1.201	1.79
Wuro Maliki	0.8	1.37	0.00528	1.76	0.31	0.12	0.7	0.2	0.5	1.33	1.83
Tarasa	0.76	1.31	0.00227	4.40	0.14	0.071	0.7	1.9	0.66	3.81	4.47
Gwandu	0.2	0.34	0.00144	4.33	0.17	0.082	0.05	1.05	0.66	1.35	2.01
Badariyya	0.32	0.55	0.00315	3.89	0.21	0.11	1.9	0.5	0.5	2.72	3.22
Garugga	0.42	0.724	0.00249	4.04	0.34	0.15	1.2	0.2	0.61	1.89	2.55
Helande	0.58	1	0.008	3.89	0.37	0.1	1.1	0.5	0.33	2.07	2.40
T/Makaranta	1	1.72	0.0014	3.5	0.37	0.095	0.55	1.65	0.66	2.665	3.33
T/Dangwari1	0.6	1.03	0.00154	2.93	0.34	0.02	1.3	0.2	0.66	1.86	2.52
Kola	0.42	0.724	0.00249	4.04	0.35	0.16	1.2	0.2	0.66	1.91	2.57
Augie	0.9	1.55	0.00239	18.8	0.34	0.08	1.15	1.15	0.83	2.72	3.55
Kwararo	0.24	0.41	0.00212	1.54	0.32	0.082	0.05	1.85	1.16	2.3	3.45
T/Dangwari2	1.34	2.31	0.00247	2.3	0.32	0.13	0.05	0.1	0.66	0.6	1.26
Kewa	0.86	1.48	0.00311	2.57	0.29	0.1	0.8	0.5	0.66	1.69	2.35
Lamude	1.08	1.77	0.00072	4.2	0.29	0.064	0.91	0.3	0.56	1.56	2.12

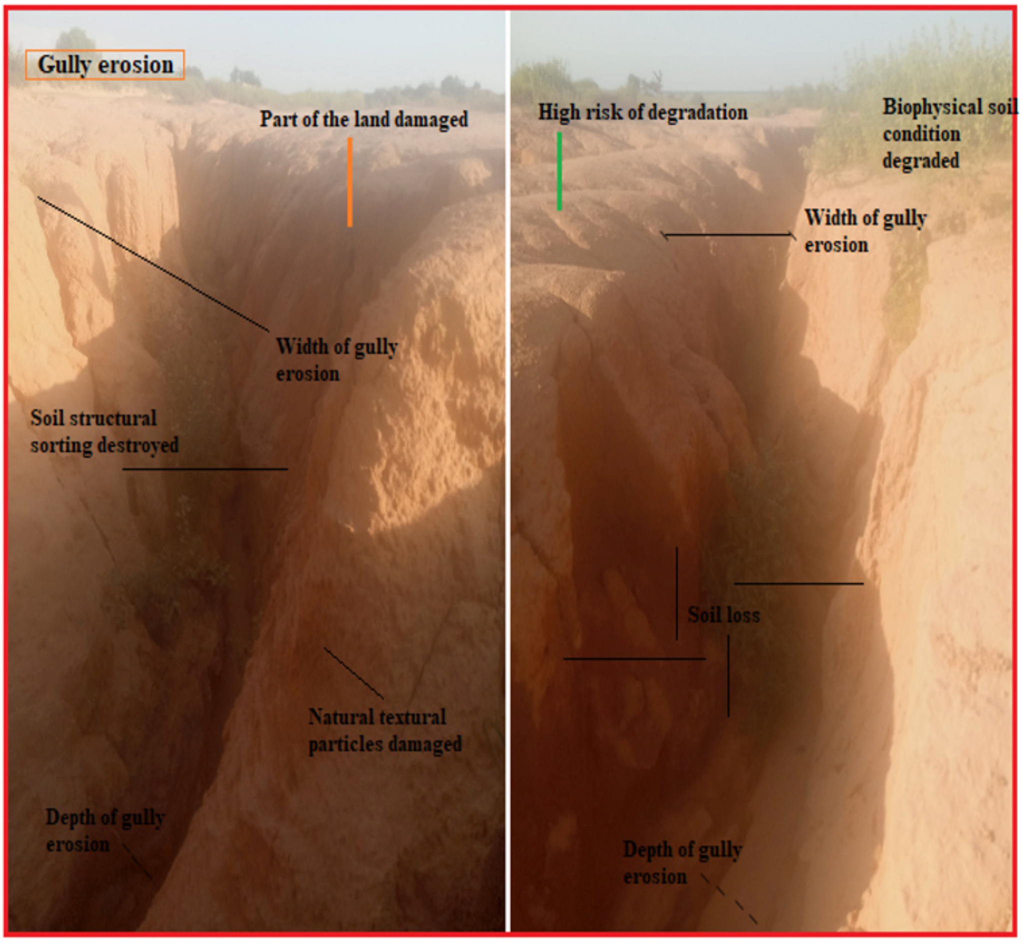

Fig. 4. Typical example of the physical impact of gully erosion in the study area

Lamude recorded the highest TEB and ECEC. These sites probably looked to receive conservation application more effectively compared to other study sites.

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 reported 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 tracked other studies, which described the physical and quantitative impact of soil erosion as nuisance to agricultural soils in Africa (Usman et al., 2017; Onyelowe, 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 already destroyed (fig. 4). This also has caused 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 soil particles (Andualem et al., 2023). This will increasingly affect the potential of soil to support plant production for food security (Andualem et al., 2023). Therefore, an increase 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 region (Andualem et al., 2023; Baade et al., 2024). The metaphors of this incident could have resulted to total decline of the overall soil quality and soil fertility status across the study sites (Usman et al., 2025). This was further explained from the overall chemical information reported in table 8. Generally, soil erosion was considered one of the environmental factors deteriorating the nutrient content of the soil, and may lead to decreased soil fertility and food security (Valkanou et al., 2022; Baade et al., 2024; Wen et al., 2024).

The physical damaged 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 (fig. 3). This is a global threat to sustainable soils and food security (Rui et al., 2024). It is also a serious environmental hazard to sustainable economy in Africa (Salhi et al., 2023). However, the configuration of this impact in the study sites is believed to have been increased due to natural condition of the drainage characteristics, which are also a subject of consideration across the study sites (table 2). Soil condition with the drainage patterns reported in this study, was considered vulnerable to soil erosion assault, and could lead to significant surface soil damage (Usman, 2024a; 2024b). Particle size characteristics revealed that soil texture was dominated by sand particles (table 7). Obviously, the sites characterized by dominant sand particles can be explain as prompt to soil erosion and could also lead to unexpected landslides annually (Baade et al., 2024). The result shows that the impact of gully erosion is advancing, and can be quantified from the the amount of soil loss from the various depths and widths recorded across the study sites (table 2-5). Perhaps, this had destroyed the productivity of soil and major soil functional services such as nutrient cycle (Usman et al., 2016; Usman et al., 2019). This shows that the management of the affected sites is required, and is useful for soil and water development in the region (Usman, 2024a; Usman, 2024b). However, one of the recent management recommendations with regards to erosion impact is the use of technological and management options, which involved multiple scientific and traditional approaches (Srinivasarao et al., 2023; Usman, 2025).

Conclusion

In the beginning, the surface soil condition was affected by gully erosion across the study sites. The assessment observed that gully erosion has caused surface soil damage and damaged 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 provided verifications, which 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 term of soil quality and soil 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. Land and soil quality are physically and chemically injured, and biophysical surface soil condition was deteriorated. This study suggests that appropriate conservation application involving both the technical and traditionally based approaches is needed. This appropriate conservation application may include the planting of shelter belt across the affected sites, advanced drainage systems and provision of water ways, inter- and mixed cropping systems.

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Ethical Statement

This work is mainly on soil and soil resources and does not involve any information on humans or animals; thus, an ethical statement is not applicable to the context of the manuscript. However, the data presented and discussion provided, is the original work to be considered for present and future reference.

Credit authorship contribution statement

Suleiman Usman designed the study, provided the practical training for field data collection in Birnin Kebbi and Gwandu. He also participated in the field data collection at Argungu and Augie sites. Aliyu Aminu and Sakaba YB received the training and collected the field data around Birnin Kebbi and Gwandu sites. Suleiman Usman calculated the data, provided the detail evaluation of soil quality and land suitability, evaluated drainage characteristics, calculated the soil erosion data, and analysed the results, statistically. Results presentation and discussion of the overall results were made by Suleiman Usman.

Declaration of competing interest

The authors declared that they have no known competing financial interests regarding the information presented and that there are no personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The results of this study were obtained from field assessment conducted in four local governments of Kebbi State Nigeria namely: Argungu, Augie, Birnin Kebbi and Gwandu. The work was part of the Institutional Based Research (IBR) supported by TetFund research programmes 2024/2025. All the data are available in the Department of Agricultural Education, Adamu Augie College of Education Argungu. Also, data can be obtained from the depository of Tetfund IBR reports in Abuja. This document is the original work approved by all the authors in January 2025 to be published by Bulgaria Journal of Soil Science, Agrochemistry and Ecology. The authors signed and agreed with the terms and conditions attached.

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