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RESEARCH PAPER

Assessment and classification of surface soil erosion impact around Dutse Jigawa State Nigeria

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Abstract

Surface soil condition from erosion-affected sites of Dutse is physically damaged by gully erosion. Book for Describing and Sampling Soils version 3.0 was used to evaluate soil texture, soil structure, soil consistency, and vegetation pattern of the 9 different study sites. The impact of soil erosion was measured on gully channels and calculated based on USDA soil erosion method. Soil quality (P-Sq) and land suitability (P-Ls) classes were evaluated by Visual Soil Erosion Approach (VSEA). Eroded soil volumes of 42.2 m^3 and 33.5 m^3 at Fagoji (FGJ) and Gidan Sarkin Askira (GSA) compared to those recorded at KRG sites (23.9 m^3). There was no reasonable variation between the sites for the condition of soil in terms of soil texture, soil structure, soil consistency and vegetation. However, a correlation analysis between the sites for the calculated values of depth and width observed that five sites (FGJ2, FGJ3, KRG1, KRG2 and GSA3) are significant ($P < 5\%$) whereas the other four sites (FGJ1, KRG3, GSA1 and GSA2) were not significant ($P = 5\%$). Soil quality and land suitability classes were evaluated as Sq2, Sq3 and Ls2, Ls3 which can be managed under careful soil conservation application whereas Sq4, Ls4 and Sq5, Ls5 are lands not suitable for agronomic production. These land conditions of the study sites were attributed to weak soil structural condition, poor vegetation and inadequate soil management. This study suggested the use of advanced soil conservation approaches such as orchard plantation, water harvesting system and drainage application in the affected sites.

Introduction

Surface soil is a shield layer that provides protection to soil materials, soil quality and soil fertility to support plants, organisms and underground soil and water systems (Usman, 2016). Soil erosion has become a serious surface soil problem and has affected the potential of soil quality and soil fertility around Dutse, Jigawa State (Usman et al., 2019). The impact of soil erosion was considered one of the most important factors threatening the sustainability of food security in this part of sub-Saharan Africa (Usman et al., 2017). Soil erosion affects the physical, biological and chemical components of soil, biota and biodiversity (Al-Shoumik et al., 2023). Soil erosion damages surface soil condition and forced the surface soil particles to detach from one place to another (Gebrie et al., 2023). This detachment of soil particles was also regarded as one of the violent environmental problems, which reduce the potential of soil to support plant and ensure food security in sub-Saharan Africa (Andualem et al., 2023). Soil erosion in this regard, removes the soil materials from the top surface soil layer (sheet), extending if not control to small channels (rills), and to deeper channels (gullies) (Andualem et al., 2023). This removal of surface soil materials take place in the form of depression by rainfall impact (splash erosion) and cause the sheet, rill and gully erosion or even overland flow sometimes (Baade et al., 2024). These forms of soil erosion, if they occurred in a given environment, the metaphors of how concentrated they are, depends largely on the nature and condition of the overall soil properties (texture, structure, consistency, drainage, organic matter content etc.), slope, vegetation cover of and land use activities (Usman et al., 2024a). Land areas subjected to continuous cultivation without proper soil management, lack of tree plantation and mismanagement of vegetation shrubs and plants, are considered highly prone to soil erosion (Usman, 2016). Under these conditions, it is noticeable that soil materials can be washed away easily by water and leaving the entire surface soil affected by various forms of soil erosion (Evans, 2013). This soil erosion impact has been described as both on-site (at the place where the soil is detached) and off-site (wherever the eroded soil gets deposited) (Usman et al., 2024b). The problem is more serious in poor vegetation areas where erosion is intense because of extreme climate conditions and poor management applications (FAO, 2023). This process of soil erosion is caused by combination of natural erosive agents, which include rainfall, wind, waves and bioturbation including human-induced factors such as over-ploughing, overgrazing, building, deforestation, forest fires and off-road vehicles (Pandey et al., 2016). According Usman et al. (2019), these erosive agents appeared to have physically caused more serious surface soil damages and bigger gully channels in some areas around Dutse. These gully channels around Dutse areas, are hastened by agricultural land use and climatic change impact, and often have been forming for many years (Usman et al., 2024a). In these areas, surface soil particles are lost by water from agricultural lands because of poor vegetation cover and improper soil management application (Usman et al., 2017). Therefore, knowing the extent of gully erosion development through assessment will help provide some solution towards a better management (Ezeh et al., 2024).

The physical and economic impact of soil erosion was considered as important driving force threatening ecological resilience, resulting in reduced land quality and productivity, increased natural disasters, and decline food security and economic development (Yang et al., 2023). Reduction in agricultural land size and soil functional service to support the production of cereals and legumes, were noted to have been occurred as a result of soil erosion impact around Dutse (Usman et al., 2019). Understanding the status of soil erosion affected sites in Dutse is therefore essential when addressing the ways to manage soil quality and increase the production of cereals and legumes in the region. Soil erosion such as gully, is destructive and cannot be managed by ploughing because of its depth, size and nature (Usman, 2007). In Dutse however, there is little information regarding the extent of soil erosion on both physical and quantitative impact. This study will provide a contribution to the management of soil and water for crop production and environmental security in the study area (Usman, 2024). Therefore, the study was aimed to assess and classify the impact of soil erosion on surface soil quality. The scope of its objectives was addressing the extent of soil erosion on physical and quantitative measures in the study area.

Materials and methods

Study area

Dutse is a capital city of Jigawa State located geographically in the north-west Nigeria. The average monthly temperature is between 30°C and 45°C and annual average rainfall is 743 mm. Elevation from sea level is between 349 m and 462 m and GPS coordinates ranging from 11.7160°N and 9.3557°E. The total population size of the human living in Dutse was estimated to account for 246,143 according to National Population Census of Nigeria (NPCN-JG, 2007). The common agricultural land use activities include monocropping, mixed farming, crop rotation, irrigation, rearing animals and fish farming. The major crops grown in Dutse and villages around are pearl millet, groundnut, maize, soybean, rice, wheat, sorghum, cowpea, sesame and date palm. The vegetation has been described as scattered trees and shrubs, which

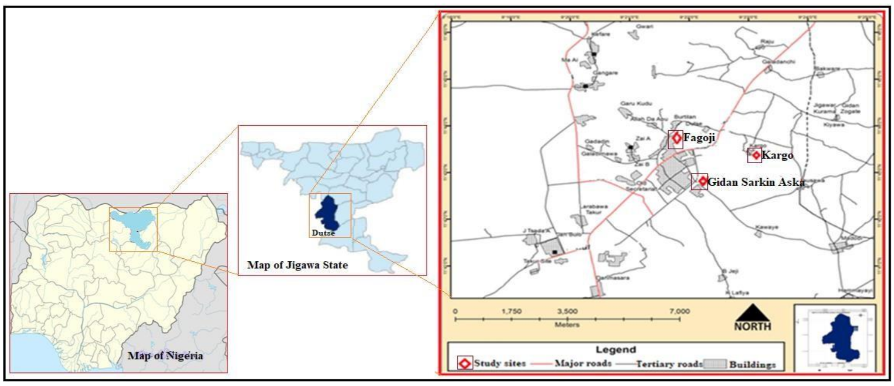

Figure 1. Map of the study area indicating the actual study sites in Dutse, Jigawa State Nigeria

include Acacia, Baobab, Neem and Palm (Dabino). However, three different study areas were selected around Dutse namely – Fagoji, Kargo, and Gidan Sarkin Aska (Figure 2).

Surface soil condition and site selection

The surface soil condition of the study site has been physically damaged by soil erosion (Figure 2). Bigger channels of gully erosion have created surface soil imbalances, which have affected the vegetation cover and plant biomass of the study sites (Figure 2). Study sites were selected based on these surface soil conditions as recommended by Evans (2013). The selection process considered the gully occurrence in the affected sites by focusing on the physical nature, size and geomorphogical feautures its channels. Both the large (bigger in size and shape) and active gullies (characterised by eroding headwalls without vegetation cover and sediment-deposited fan) are believed to have generated significant amounts of sediment and have caused serious damage to surface soil condition of the selected study sites (Figure 2).

Figure 2. Typical example of the surface soil condition of the study area

The 3 selected areas around Dutse [Fagoji, Kargo and Gidan Sarkin Aska (Figure 2)] were corded as Fagoji (FGJ), Kargo (KRG), and Gidan Sarkin Aska (GSA). However, at each of the study area, 3 different sites were also assessed and evaluated. A total of 9 different sites were covered in the study region: FGJ1, 2 and 3; KRG 1, 2 and 3; and GSA1, 2 and 3 accordingly. The overall assessment was established across these selected sites by considering the different land use practices, vegetation cover and surface soil condition. The local slope gradient of the selected areas varied from length, depth and width, which was of the typical land topography of the study sites. Physically, these sites consist of few trees and shrubs, and mostly dominated by silt and fine sand.

Soil sampling and analysis

Four different composite soil samples were collected using soil auger from the field at each of the study sites. Two of these soil samples were taken from the upper part of the gully site whereas the other two were taken from the lower part of the gully channel. A total of nine (9) different composite soil samples collected from 90 different points (30 x 3 = 90) were taken to the lab for soil textural analysis. This soil textural analysis was performed based on simple jar test which provided a typical separation of percentage sand, silt and clay (Usman, 2013). Book for Describing and Sampling Soils version 3.0 (Schoeneberger *et al.*, 2012) was used to evaluate soil structure, soil consistency and vegetation.

Measurement of the gully erosion

This study adapts the concept of direct measurement of soil erosion at *in situ* level introduced by United State Department of Agriculture (USDA, 2012). Range poles were used to earmark the affected areas and also to identify point-by-point for measurement of the affected area. These range poles were inserted into the soil along the slope transects

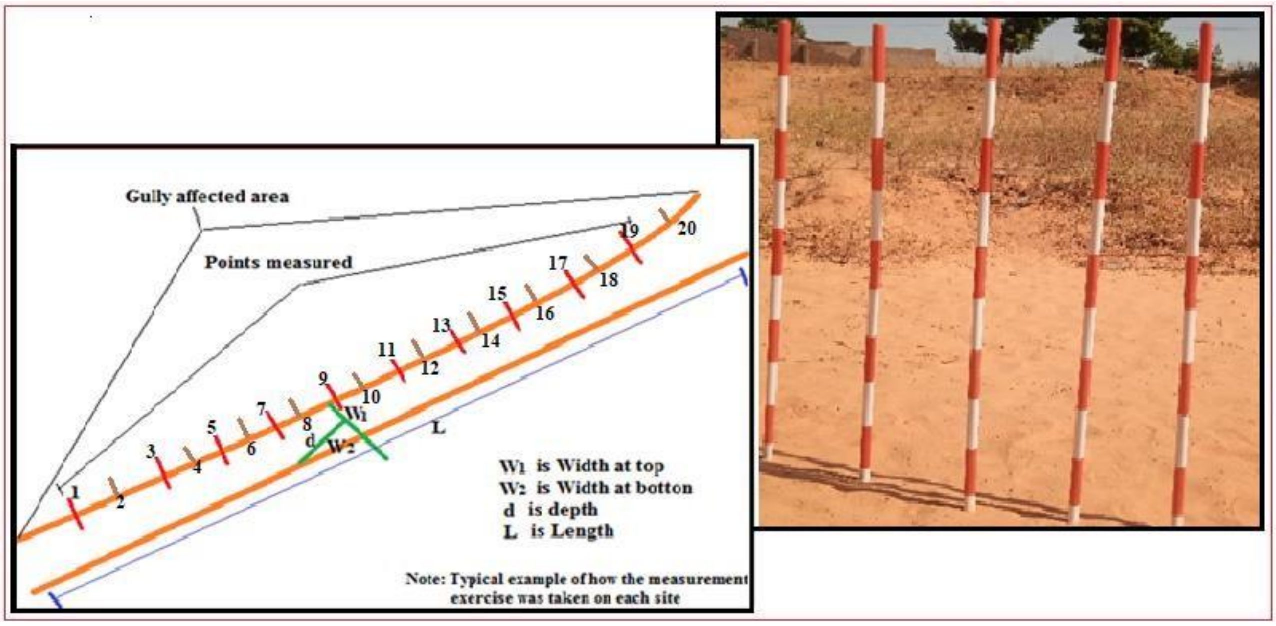

Figure 3. Example of the field layout for measurement exercise

with 3 m to 5 m intervals across the slope. However, for each transect, five poles were spaced at 5 m intervals across the entire gully channel. The lengths of the poles that were left exposed above the soil surface were used as reference point for the measurement exercise. This measurement took place in the field and covered 20 different measurements transects or points on each of the gully area (Figure 3). Selection of these measurement points was based on random sampling within the affected area. It covers the top width (W_1), width at bottom (W_2), depth (d) and length (L).

Likewise, soil quality (P-Sq) and land suitability (P-Ls) classes were evaluated by Visual Soil Erosion Approach (VSEA) introduced by Usman et al. (2024) for agronomic and management application (Table 1).

The overall results were used to determine the volume of soil loss at each study site, and calculated according to USDA (2012) formula:

$$V = L \times \frac{W1+W2}{2 X d}$$

Table 1. Soil quality (P-Sq) and land suitability (P-Ls) description guide (Usman *et al.,* 2024)

a) P-Sq[1]	Sq1	Very small-size channel of sheet erosion: 0 – 5 cm width and depth
	Sq2	Small-size channel of sheet erosion: 6 – 10 cm width and depth
	Sq3	Small-size channel of rill erosion: 11 – 20 cm width and depth
	Sq4	Large-size channel of rill erosion: 21 – 30 cm width and depth
	Sq5	Gully surface erosion: >30 cm width and depth
b) P-Ls[2]	Ls1	Good land: few indications of very small-size channels of sheet in the study sites at that time of assessment in the field
	Ls2	Moderately good land: few small-size channels of sheet erosion in the study sites at that time of assessment in the filed
	Ls3	Poor land: 20% of the site is affected by small channels of rill in study sites
	Ls4	Very poor land: >20% of the site is affected by large channels of rill in the study sites at that time of assessment in the field
	Ls5	Bad land: significant portion of the land is affected by gullies in study sites

[1, 2] P-Sq and P-Ls classes are described based on VSEA. The measurement was carried out in the field

Where:

V = volume of soil loss
L = length
W_1 = the average top width measured from the gully channel
W_2 = the average bottom width measured in the gully channel
d = the average depth of gully erosion

Statistical Analysis

All the data was run for statistical analysis using excel to compare the sum, average, minimum and maximum values of depth, width at top and width at bottom between the therww (3) study sites.

Results

Soil physical properties, vegetation, management and drainage condition

Table 2 presents the results of particle analysis, textural class, soil structural class and vegetation. Across all the study sites, percentage sand particles were found to be the dominant texture fraction. Soil structural class appeared to be weak and structureless whereas vegetation cover was evaluated as poor and very poor. Initial background of the surface soil condition prior to this assessment has also confirmed that the vegetation cover is poor (Figure 2). A significant decline of surface soil quality was noted from the results of soil structural classes across all the study sites (Table 2).

Table 2. Soil texture, structure and vegetation condition of the study sites

Site	% Sand	% Silt	% Clay	Texture Class	Soil Structural Class	Vegetation
FGJ1	82	8	10	Sandy Loam	Weak	Poor
FGJ2	84	6	10	Sandy Loam	Weak	Poor
FGJ3	80	6	15	Fine sand	Structure-less	Very-Poor
KRG1	80	8	12	Sandy	Structure-less	Poor
KRG2	81	5	15	Sandy	Structure-less	Poor
KRG3	81	7	12	Sandy	Structure-less	Poor
GSA1	81	8	11	Sandy loam	Structure-less	Very-poor
GSA2	82	8	10	Sandy	Weak	Very-poor
GSA3	85	5	10	Sandy	Weak	Very-Poor

Table 3 explained the management and drainage condition of the study sites. There are indications of farmers' efforts through manure and compost application to help improve the condition of the soil (Table 3). However, both the soil and crop management applications, which also reported the use of cow dung, house refuse and inorganic fertilizers under mixed and mono-cropping systems, are not sufficient probably due to drainage conditions of the sites (Table 3). The drainage pattern either drained, well-drained or excessively drained are likely to cause surface soil deterioration leading to surface soil damage and occurrence of soil erosion.

Table 3: Management practices and drainage condition of the study sites

Sites	Management practices (soil)	Management practice (crop)	Drainage class
FGJ1	Manure, inorganic fertilizer	Mixed-cropping	Well Drained
FGJ2	Cow dung, inorganic fertilizer	Mono-cropping	Drained
FGJ3	Compost manure	Mixed-cropping	Excessively Drained
KRG1	Manure, cow dung	Mono-crop	Well-drained
KRG2	Inorganic fertilizer	Mono-crop	Drained
KRG3	Inorganic fertilizer	Mono-crop	Excessively Drained
GSA1	Inorganic fertilizer	Mono-crop	Well Drained
GSA2	House refuse, cow dung	Mixed-cropping	Drained
GSA3	Inorganic fertilizer	Mono-crop	Excessively Drained

Length, width and depth of gully erosion

Table 4 presents the data recorded for length, width and depth of gully erosion whereas the averages for these parameters are presented in Table 5. The observation was based on the measurement exercise in the field. The highest depth was recorded around Gidan Sarkin Aska (GSK) sites compared to those recorded around Fagoji (FGJ) and Kargo (KRG). However, higher width was recorded at KRG sites, which appeared to be bigger than those recorded at FGJ and GSA, respectively. The total length measured at FGJ1 and GSA3 were higher than all the sites across the study area. The expanding of gully erosion across these study sites are defined by these parameters, and appeared to have been destroying the aggregate structure and reduce the surface soil quality as reported in Table 2 and 3. Width expanded with the damage of soil structure and can be noticed by distance across the gully channels, which is physically damaging the end-to-end portions of the gully in the study sites. The correlation analysis shows that sites at FGJ2, FGJ3, KRG1, KRG2 and GSA3 are significant (P < 5%). However, sites around FGJ1, KRG3, GSA1 and GSA2 were not significant (P = 5%).

Table 4. Depth, width at top and bottom and length of gully erosion in the study sites

Site	Depth (m)	Width top (m)	Width bottom (m)	Length (m)
FGJ1	19.2	14.0	12.1	45.50
FGJ2	16.1	56.3	53.6	25.5
FGJ3	52.1	50.1	42.2	39.0
KRG1	8.9	71.3	57.1	32.0
KRG2	15.0	89.4	81.4	35.0
KRG3	11.5	87.6	89.3	26.0
GSA1	77.1	52.5	43.5	35.5
GSA2	74.6	28.9	22.4	27.0
GSA3	80.3	61.0	52.2	43.3

Table 5. Correlation analysis of the gully parameters in the study sites

Site	Depth (m)	Width top (m)	Width bottom (m)
FGJ1	-0.97079^{NS}	-0.93606 ^{NS}	-0.95706 ^{NS}
FGJ2	0.666784*	0.749371*	0.704476*
FGJ3	-0.67054*	-0.57917*	-0.63123*
KRG1	-0.90355*	-0.84723*	-0.88015*
KRG2	0.980868*	0.993137*	0.998659*
KRG3	0.998779 ^{NS}	0.988647 ^{NS}	0.99786 ^{NS}
GSA1	-0.97072 ^{NS}	-0.93597 ^{NS}	-0.95699 ^{NS}
GSA2	-0.99539 ^{NS}	-0.97734 ^{NS}	-0.98909 ^{NS}
GSA3	-0.95767*	-0.91743*	-0.94148*

Note: NS Signifies not significant at P = 5%
* Signifies significant at P < 5%

Volume of soil loss, sum, maximum and minimum

The basic geometric components of the width and depth, and the volume of soil loss across all the study sites are presented in Table 5. Sites GSA1, GSA3 and FGJ1 recorded the highest volume of soil loss whereas sites FGJ2 and GSA2 recorded the lowest volume. This soil loss was calculated from the width, depth and length of gully erosion at each of the study sites. This soil loss increased in response to the rise in these three parameters. Sites recorded the higher width, depth and length are noted to have an increased in soil loss. This means that the volume of soil loss at each of the study sites depend entirely on the sum, average, maximum and minimum values of the parameters measured (Table 6).

Table 6. Sum, maximum and minimum values of depth and width in the study sites

Factor	Value	FGJ1	FGJ2	FGJ3	KRG1	KRG2	KRG3	GSA1	GSA2	GSA3
Depth (d m)	Sum of d	19.2	16.1	52.1	88.9	11.5	15.0	77.1	74.3	80.3
	Average d	9.6	80.5	26.0	8.9	57.0	79.0	17.0	37.15	40.5
	Maximum d	9.3	9.5	4.9	11.2	9.4	9.5	8.0	6.0	5.5
	Minimum d	3.1	2.3	1.1	1.8	1.0	3.9	1.6	2.0	2.6
Width top (W_1 m)	Sum of W_1	14.0	56.3	50.1	71.3	87.6	89.4	52.5	28.9	61.0
	Average W_1	69.5	28.1	25.0	71.3	43.7	44.7	52.5	14.4	30.4
	Maximum W_1	9.5	4.0	3.6	7.3	55.0	57.1	3.0	6.7	45.0
	Minimum W_1	3.4	1.5	6.0	3.0	37.0	32.0	2.2	3.5	3.8
Width	Sum of W_2	12.1	25.5	42.2	57.1	89.3	81.4	43.5	22.4	52.2
bottom (W_2 m)	Average W_2	61.8	26.8	21.3	57.1	44.6	40.9		11.1	26.4
	Maximum W_2	8.6	4.3	3.2	9.0	60.0	51.2		6.2	43.7
	Minimum W_2	3.1	1.5	4.0	3.7	3.4	2.9	1.5	1.7	3.9
Soil loss (m^3)		30.8	9.1	42.2	23.9	20.5	19.5		11.5	30.5

Table 7. Soil loss, soil quality and land suitability classes in the study sites

Site	Soil loss (m^3)	Soil quality class (P-Sq)	Land suitability class (P-Ls)	Label of the surface condition
FGJ1	30.8	Sq4	Ls4	Notably damaged
FGJ2	9.10	Sq2	Ls2	Small portion damaged
FGJ3	42.2	Sq5	Ls5	Bad land
KRG1	23.9	Sq4	Ls4	Notably damaged
KRG2	20.5	Sq3	Ls3	Partly damaged
KRG3	19.5	Sq3	Ls4	Notably damaged
GSA1	33.5	Sq5	Ls5	Partly damaged
GSA2	11.5	Sq3	Ls3	Partially damaged
GSA3	30.5	Sq4	Ls4	Notably damaged

Soil loss, soil quality and land suitability classes

Table 7 shows the soil quality and land suitability condition for agricultural and management application. Compared with the volume of soil loss across the study sites, 3 major classes of soil quality and land suitability were evaluated (Table 7). Except for Sq2, Sq3 and Ls2, Ls3 which can be managed under careful soil conservation application, the other sites appeared to be partially damaged and bad condition. These Sq4, Ls4 and Sq5, Ls5 are lands not suitable for agronomic production. Significant portion of the land was destroyed and management application required is likely to be more costly.

Discussion

This study aligns with previous studies in Nigeria and Africa that assessed the impacts of soil erosion from agricultural soils (Usman et al., 2017; Onyelowe, et al., 2018; Ezeh et al., 2024). It is also tallied with other similar studies (Stott, 1997; Shi et al., 2011) that measured soil losses and made comparisons between the affected sites. Eroded soil volumes of 42.2 m^3, 33.5 and 23.9 m^3 at FGJ and GSA interpreted within the same range of 21.47 m^3 and 45 m^3 recorded by Usman et al. (2019) in Dutse. This physical and quantitative impact of the gully erosion across the study sites positioned the surface soil properties at a very high risk of damage as already had destroyed the soil functional services of the area (Evans, 2013). This also has caused a serious surface soil deterioration that could probably affect the physical, biological and chemical properties of the in the study sites (Al-Shoumik et al., 2023). The detachment of soil particles around the sites recorded the highest volume of soil loss as observed around FGJ and GSA is a serious threat to soil biological biodiversity and soil productivity (Usman et al., 2016). At very high rainfall intensity, this detachment of soil particles across the study sites could lead to greater deterioration of soil particles and surface soil damage (Gebrie et al., 2023). In this regard, the impact of gully erosion around Dutse is likely to reduce the potential of soil to support crop production and ensure food security (Andualem et al., 2023). Therefore, increase of width, depth and length of gully erosion in the study sites around Dutse is possible to cause frequent landslides and advanced soil loss in all the sites (Andualem et al., 2023). The limited plant biomass and poor vegetation cover in the study sites are factors, which could also lead expanding of gully erosion and removal of surface soil materials long time ago (Baade et al., 2024). The metaphors of this incident could had resulted to total decline of the overall soil properties including the organic matter and organic carbon content of the study sites slope (Usman et al., 2024a).

The physical damaged caused by the expanding of gully channels from end-to-end portions of the affected area at each of the study site, is an indication of impossibility for agricultural cultivation (e.g. Figure 2). The configuration of these gully channels across the study sites is believed to have been increased due to natural condition of the drainage patterns, which were described as drained, well drained and excessively drained (Table 2). This had probably given direction for gully erosion to expand by progressive head cutting collapsed and damaged the surface soil of the study sites (Figure 2). The percentage width and depth that were calculated on the volume of soil loss across the study sites (Figure 4), can be linked to the overall surface soil conditions, management application, vegetation forms and drainage classes, which were characterized as weak, structureless and poor (Table 2). Soil condition with this specification, was considered vulnerable to soil erosion assault, and could lead to total surface soil damage (Usman, 2024).

Obviously, the 3 sites were characterized by dominant sand particles, which can be explained as instable due to the nature and condition of the surfaces that appeared to be homogeneous in nature (Table 1). Usually, soils with these textural particles may probably experience slow erosion processes, which over time may create deep-cut and wider channels leading to surface damage and landslides (Baade et al., 2024). This is likely to be applicable to most of the study sites as

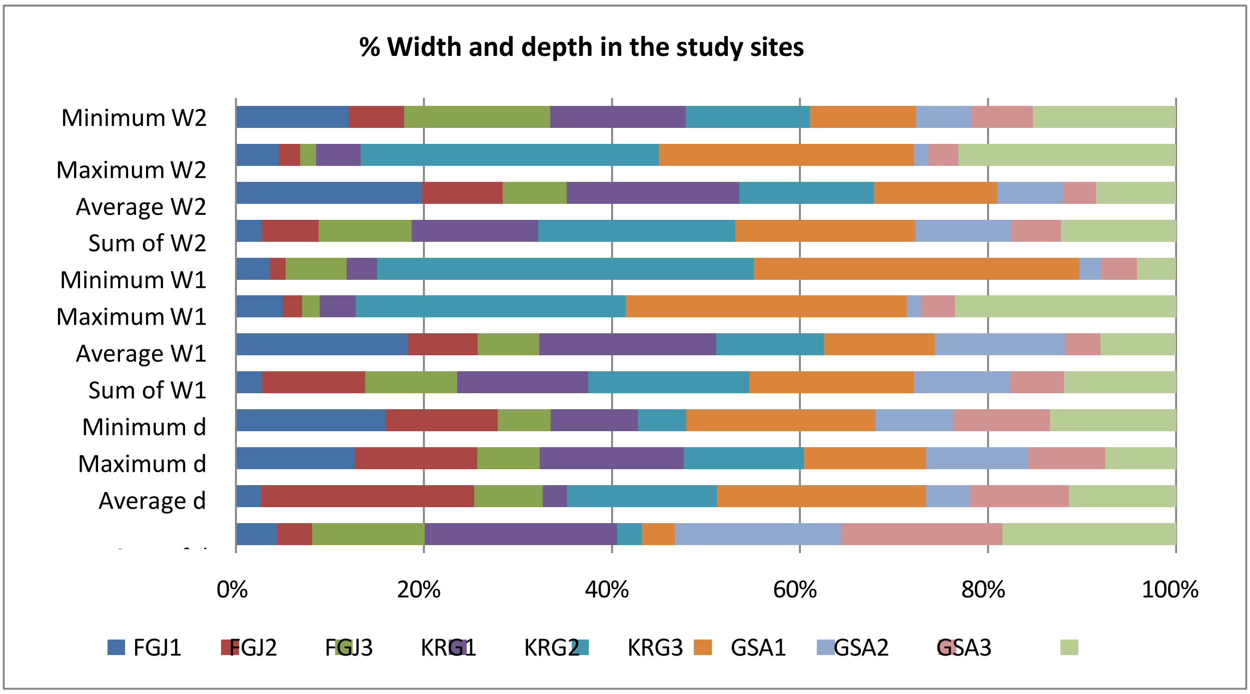

Figure 4. Percentage depth and widths across the study sites

indicated by the correlation analysis (Table 4). The result shows that gully erosion has an advance soil impact over any other type of soil erosion, and can be verified from the fact that the amount of soil loss from the various depths and widths recorded across the study sites (Table 3, 5). Perhaps, this had destroyed significantly the soil functional services, which are playing major roles for ensuring food security and biological biodiversity in the study area (Usman et al., 2016; Usman et al., 2019).

Conclusion

Initial surface soil and vegetation condition were affected by gully erosion many unknown years ago. The study has shown that the gully erosion increased as width, depth and length expanded. The characteristics of soil textures and soil structural formation plus vegetation condition across the study sites have also contributed to the increased of gully erosion. Most of the soils are structureless and vegetation, are poor; these yielded many imbalances, which have contributed to the soil damages in the study area. Differences of the volume of soil loss in the study sites are not much and many sites are related to others in term of depth, width and length. However, the evaluation of soil quality and land suitability classes indicated that the soil condition was deteriorated and the use of land for crop production will require management effort. Planting shelterbelt and forest regeneration along the affected sites are recommended for long term sustainability of the agricultural soil in the study region. Thus, the use of VSEA for other similar soils/environment affected by erosion requires through assessment and evaluation of the major components of environment (e.g. soil properties, plant biomass, vegetation, socio- economic factors such as poverty, deforestation etc.) in the study area. This will validate the efficiency and an adaptability of VSEA to other similar soils/environment across the African drylands, further.

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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.

Credit authorship contribution statement

Suleiman Usman designed the study, calculated the data and analysed the results. Suleiman Usman, Yusuf Aliyu Firi collected the data in the field. Bashir Uba Sani helps in field design.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that might appear to influence the work reported in this paper.

Data availability

The results of this study were obtained from field assessment conducted in Dutse, Jigawa State Nigeria. The work was part of the Institutional Based Research (IBR) supported by TetFund research programmes. All the data are available in the Department of Soil Science, Faculty of Agriculture, Federal University Dutse, and also, can be obtained from the depository of Tetfund IBR reports in Abuja, Nigeria.

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