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SOIL DEGRADATION ASSESSMENT IN SELECTED LAND-USE TYPES OF KANO STATE, NIGERIA

*[1]Hussaini Auwalu Yau, [1]Mohammed Juji Magaji, [3]Abdurrahman Gwadabe Musa, [2]Ahmad Maitama Zakariyya, [1]Muntaka Shuaibu Yusif, and [4]Zakariyya Auwalu Yau

[1]Department of Soil Science, Faculty of Agriculture, Bayero University Kano, Nigeria
[2]Department of Agronomy, Faculty of Agriculture, Bayero University Kano, Nigeria
[3]Department of Crop Science (Agronomy), University of Abuja, Nigeria
[4]Department of Pure and Industrial Chemistry, Bayero University Kano, Nigeria
***Corresponding author:** hussainyau01@gmail.com; **ORCID Number:** 0009-0004-6144-282X

ABSTRACT

This study assessed the status of soil degradation across three prevalent land uses: farmland, grazing land, and tree plantations in Kumbotso Local Government Area, Kano State, where a total of eighteen (18) samples (six per land use) using simple random soil sampling methods were collected within the depths of 0-20 cm and composites of two samples for each land use were made and tested for physical (bulk density, texture) and chemical (N, P, K, ESP, BSP, EC, OM) properties. The laboratory results obtained were compared with the standard indicators and criteria for land degradation assessment according to FAO, 1979. The results revealed varying degrees of degradation; physical degradation was evident with tree plantations and grazing lands exhibiting higher bulk density (1.4–1.7 g cm^{-3}). Most soils textureof the area were sandy (>85% sand), though some farmlands showed improved silt content (120–130 g kg^{-1}). Chemical degradation was discerned with low P (6.16–51.9 mg kg^{-1}), N (0.1–0.19%), and K (0.33–0.43 cmol/kg) respectively, organic matter depletion (0.58–1.91%) and BS below (1%) signifying very high degradation were observed, while some sites have shown high ESP (up to 31%). EC values in all the sites are within the standard (< 2 dS/m). From the findings, the comparison of the status of the soil's physical and chemical properties with the FAO standard shows that the area is undergoing degradation. Therefore, sustainable land management strategies, including rotational grazing, organic amendments, gypsum application, and agroforestry, were recommended to enhance the soil structure and fertility of the study area. Additionally, policy interventions for promoting soil conservation and farmer education are also needed to combat ongoing degradation and ensure long-term agricultural productivity.

Keywords: Land use, Nutrient depletion, Soil degradation, Sustainable management.

INTRODUCTION

Soil is a dynamic, non-renewable resource that plays a critical role in agriculture and ecosystem health (Shilewant *et al*., 2020). Soil is involved in several ecosystem services that are of utmost importance for the maintenance of life on the planet (Rosas *et al*., 2025), such as provisioning (food, fiber, and timber production), regulating (climate, flood, and water regulation), cultural, and supporting (nutrient cycling and soil formation) (Silvero *et al*., 2023). Additionally, soils support earth system functions that contribute to the well-being of ecosystem services. The suitability of soil for these purposes depends on its chemical and biological properties, as noted by Liu *et al*. (2020). It also serves as a foundation for agricultural systems, impacting food security and ecosystem health (Pandey *et al*., 2024). Over time, soil supports biodiversity, controls nutrient availability, and reduces erosion, which are critical for sustainable agriculture; therefore, effective soil management strategies are essential to address degradation and maintain soil health, which is vital for sustainability of future agricultural productivity (Handayani & Hale, 2022). According to Laudicina *et al*. (2023), the quality of soil refers to its ability to function as a living system within the limits of ecosystems and land use. This includes supporting productivity, promoting air and water quality, and ensuring the health of plants, animals, and humans. The contemporary understanding of soil quality highlights its role in sustaining functions. However, it is important to acknowledge that there are challenges in conducting assessments. One key challenge is the integration of indicators and the need to enhance approaches. This is crucial for ensuring that assessments of soil quality make meaningful contributions to land management and policy development, as highlighted by Oviedo-Celis *et al*. (2024).

Agricultural land degradation is a widespread issue in sub-Saharan Africa. It is often seen as a downward spiral caused by overexploitation of farming practices, low external inputs, and improper management. This accelerated degradation is leading to the shrinking of soil resources, particularly in regions with harsh climates and delicate soils (Saturday, 2018). Soil degradation refers to the decrease in quality (physical, chemical, and biological deterioration) of soil due to its use primarily in agricultural, grazing, or industrial activities (Rosas-Medina *et al*., 2020). This process can lead to changes in properties such as soil texture (Rowell, 2014); chemistry, often influenced by fertilizer and pesticide application (Rosas-Medina *et al*., 2020), which can cause soil acidification (Siles and Margesin, 2016); and its components, including vegetation cover loss, which contributes to soil erosion prevention (Rosas-Medina *et al*., 2020). It is important to note that human activities are the primary cause of soil degradation, resulting in impacts on soil biodiversity (Chakravarthy and Sridhara 2016). According to Edrisi *et al*. (2022), the expansion of infrastructure and urbanization is a significant factor in land degradation as it leads to the encroachment on natural habitats, these activities account for approximately 14.17% of the drivers of degradation. It is crucial to recognize that the process of degradation extends beyond agricultural consequences; it also has implications for biodiversity loss and increased poverty (Badapalli *et al*., 2023). For society to make real advancements in agriculture, it is important to prioritize maintaining or enhancing soil quality based on a series of indicators. These indicators can be monitored over time to help us reach ecological productivity. The proposed indicators for soil quality and productivity encompass factors such as organic matter (or carbon), soil structure, conservation, and soil food web health (Abosede *et al*., 2015).

According to Danhassan *et al*. (2024), there have been shifts in both land-use and land cover (LULC) in the Kumbotso Local Government Area in Kano State over the past few decades. The area has experienced significant transformations as a result of the growth in both agricultural activities and urbanization, leading to alterations in the landscape. Currently, there is a scarcity of data regarding how land-use changes over time and space in this area. According to Huang *et al*. (2020) and Xiao *et al*. (2020), this lack of data is posing a challenge to the development of land management policies and practices.

In this study, three land-use sites were selected within the Kumbotso Local Government Area as the focus. These are farmland, grazing land, and tree plantations. The main aim of this study was to assess the degradation status of soils in selected land uses of Kumbotso, Kano State, using some quality indicators, while the objectives were to (1) establish the degree of degradation of the soil of the study area using standard indicators and criteria for soil degradation assessment (FAO, 1979). (2) Suggest modest recommendations on the rehabilitation strategies for the proper management of such degraded soils.

MATERIAL AND METHODS

Experimental Sites

The field research took place in the Kumbotso Local Government Area of Kano State, Nigeria. Kumbotso Local Government Area was established in 1976. It covers an area of 158 km². It is home to a population of two hundred and ninety-four thousand three hundred and ninety-one (294,391) people with a population density of 2,197.47 inhabitants per km² (NPC 2006). According to the National Population Commission, in 2006, it was projected that the population would reach 374,200 by 2011. The region is situated at an elevation of 450 meters above sea level. The area is located between latitudes 11° 53' 17" N and longitudes 8° 30' 10" E on the map. This area's vegetation is categorized as savanna, and it receives between 850 and 870 mm of rainfall annually.

Soil Sampling/Analysis

Soil samples at a depth of 0–20 cm were collected randomly in each of the study sites using a core sampler and soil auger from three different land uses: farmland, grazing land, and tree plantation at Kumbotso Local Government Area. The samples were air-dried, later crushed with a pestle, and sieved through a 2 mm sieve. A total number of eighteen (18) samples were collected, six (6) from each land use, and the sieved samples were packed and labeled for routine laboratory analysis. Particle size analysis was done using the Bouyoucos hydrometer method (Gee and Bauder, 1986). Bulk density was determined using minimally disturbed core samples (as described by Grossman and Reinsch, 2002). Available P was determined in the sand using the Bray-1 method (Bray and Kurtz, 1945). Organic carbon was analyzed by the dichromate wet oxidation method of Nelson and Sommers (1982). Determination of total nitrogen was analyzed using the micro-Kjeldahl distillation method (Bremner and Mulvaney 1982). Exchangeable cations (Ca, Mg, K, and Na) were extracted using an ammonium acetate solution at pH 7.0 (Thomas, 1982). The contents of exchangeable bases were read using atomic absorption spectroscopy (AAS) and a flame photometer. Base saturation percentage was calculated as the proportion of exchangeable bases to cation exchange capacity (CEC), while the exchangeable sodium percentage was calculated as the proportion of exchangeable Na to CEC using the method described by the U.S. Salinity Laboratory Staff (Richards, 1954). Effective cation exchange capacity (ECEC) was calculated by summing up the exchangeable bases plus the exchangeable acidity (Sumner and Miller 1996). Cation Exchange Capacity (CEC) was determined using a neutral, 1N ammonium acetate method. The collected data were subjected to analysis of variance (ANOVA) with the aid of GENSTAT 17th edition. Significant mean values were separated using the Student-Newman-Keuls Test (SNK).

Soil Degradation Assessment

The indicators and criteria for land degradation assessment outlined by the Global Assessment of Land Degradation were used to evaluate the levels of degradation in the studied soils. The analytical data from each land use were carefully compared with the land degradation indicators to assess the levels of degradation of the land uses, as shown in Table 1 (FAO, 1979).

Table 1: Indicators and Criteria for Land Degradation Assessment

Indicators	Degree of degradation			
Parameter	**1**	**2**	**3**	**4**
Physical Degradation				
Soil Bulk density (gcm^{-3})	<1.5	1.5-2.5	2.5-5.0	>5
Chemical degradation				
Content of N element (multiple decreases) N (%)	>0.13	0.13-0.10	0.10-0.08	>0.08
Content of Phosphorus Element (mg kg^{-1})	>8	8-7	7-6	<6
Content of Potassium Element (cmol (+) kg^{-1})	>0.16	0.16-0.14	0.14-0.12	<0.12
Content of ESP (increase by 1% of CEC)	<10	10-25	25-50	>50
Base saturation (decrease in more than 50%)	<2.5	2.5-5	5-10	>10
Excess salt EC (dSm^{-1})	<2	2-3	3-5	>5
Biological degradation				
Content of humus in soil (%)	>2.5	2.5-2.0	2.0-1.0	>1.0

Source: FAO (1979)

Key: Class 1: Non-slightly degraded
Class 2: Moderately degraded
Class 3: Highly degraded
Class 4: Very highly degraded

RESULTS AND DISCUSSIONS

Physical Properties of Soil in the Study Area

From the results presented in Table 2, the bulk density values ranged from 1.3 g cm^{-3} in (F1) to 1.7 g cm^{-3} in (T2) (Table 2). Higher bulk density was observed in (T2) and some grazing lands (G2, G3), suggesting soil compaction due to frequent trampling by livestock, which restricts root penetration, reduces water infiltration, and contributes to land degradation. These findings align with Ahad *et al*. (2015) work on soil management, which noted that higher bulk density often correlates with reduction in porosity, leading to impacts on root penetration and water retention. It is worth noting that grazing lands showed moderate bulk density (1.4–1.6 g cm^{-3}) (Table 2). The study conducted by Bogunović *et al*. (2022) found that moderate grazing, while still increasing bulk density, does not induce as severe compaction as heavy grazing. Additionally, research by Lai & Kumar (2020) through a meta-analysis confirmed that moderate grazing significantly increases bulk density, with heavy grazing showing even greater compaction effects. In a study conducted by Hendricks *et al*. (2019), it was discovered that pastures in Southern Piedmont had an average bulk density of 1.62 g cm^{-3} at a depth of 5 to 10 cm, indicating that grazing activities can lead to soil compaction. On the other hand, lower levels of bulk density observed in farmlands (F1, F3) (Table 2) can be attributed to practices such as incorporating organic matter into the soil structure through tillage techniques, which help enhance its quality. According to research by Wang *et al*. (2017) and Zhu *et al*. (2023), there is a connection between higher levels of SOC (organic carbon) in the soil and lower bulk density, suggesting that incorporating organic matter into the soil can improve its structure by increasing porosity. However, it's important to consider that changes in soil microbial communities influenced by land use can also play a role in affecting bulk density through their impact on soil structure as well as dynamics (Zhu *et al*., 2023). In addition, most of the studied soils have a sand-dominated texture content exceeding 85% across all land uses, with (F3) and (T1) exhibiting the highest sand content (890–910 g kg^{-1}) (Table 2). This high sand content could be attributed to processes such as the washing away of fine materials by water erosion and the blowing of fine particles by wind erosion, which can impact soil structure and nutrient retention, as reported by Lema *et al*. (2019). Similarly, while sandy soils have good drainage, it's important to acknowledge that they generally have lower abilities when it comes to retaining moisture or nutrients, which can ultimately affect crop yields (Sani *et al*., 2023). An effective method for improving sandy soils is the use of cover cropping. This practice helps in increasing soil organic matter (SOM) and availability of nutrients. The positive effects of cover cropping on citrus orchards in Florida are supported by evidence showing higher nitrate concentrations and SOM levels (Brewer *et al*., 2023). According to Xu *et al*. (2019), combining cover cropping with organic amendments like horse bedding further contributes to soil health by enhancing water holding capacity and increasing organic matter content. Furthermore, the loamy sand texture in F1 and F2 exhibits a slightly better silt content than other sites, with silt values ranging from 120 to 130 g kg^{-1} (Table 2), suggesting an optimal texture for enhancing microbial activity crucial for supporting crop growth, as highlighted by Ye *et al*. (2024).

The assessment of soil properties presented in Table 4 indicates that different land-use sites show degrees of degradation based on bulk density ratings; specifically, (F2), (G3), (T2) and (T3) were classified as moderately degraded (MD). However, it is noted that some sites, including (F1), (F3), (G1), (G2), and (T1), were slightly degraded (SD) when considering critical levels by FAO (1979). This comparison highlights a relationship between land use practices. According to Kahsay *et al*. (2023) recognizing the impacts of land use can help in developing management approaches tailored to specific soil conditions. These practices play a role in preserving soil health and productivity.

Table 2. Physical Properties and Textural Class of Soil

Land Uses	Bulk Density (gcm^{-3})	Sand (g kg^{-1})	Silt (g kg^{-1})	Clay (g kg^{-1})	Textural Class
F1	1.3	860	120	20	Loamy Sand
F2	1.6	850	130	20	Loamy Sand
F3	1.4	890	90	20	Sand
G1	1.4	880	70	50	Sand
G2	1.4	880	100	20	Sand
G3	1.6	910	70	20	Sand
T1	1.4	910	70	20	Sand
T2	1.7	930	50	20	Sand
T3	1.6	900	80	20	Sand

Key: F1: Farmland 1st location, F2: Farmland 2nd location, F3: Farmland 3rd location, G1: Grazing land 1st location, G2: Grazing land 2nd location, G3: Grazing land 3rd location, T1: Tree plantation 1st location, T2: Tree plantation 2nd location, T3: Tree plantation 3rd location.

Chemical Properties of Soil in the Study Area

The results of the soil chemical properties are presented in Table 3. Generally, the electrical conductivity of the soils was slightly degraded in all land uses. From the results obtained, it was observed that the values were elevated on (G1, 0.95 dS/m) and (T1, 0.82 dS/m) (Table 3). Molua (2021) reported that grazing lands have higher conductivity, while tree plantations can provide other ecological benefits, such as enhancing biodiversity and sequestering carbon, which are crucial for sustainable land management. The nitrogen levels in the soils in most land uses were slightly degraded, except in F2, F3 and T1 indicating a moderately degraded situation. This indicates a level of degradation, suggesting that these areas may be affected by farming practices without proper use of fertilizers, leading to lower N (0.1%). The decrease in nitrogen content aligns with research that shows degraded soils often suffer from nutrient deficiencies (Qiang *et al*., 2021). According to Abosede *et al*. (2015), nitrogen is recognized as an element for plant growth, development, and reproduction. It is by far the most limiting element, especially in the tropics, where organic matter decomposition is rapid and nitrogen released from the process is easily lost through leaching or evaporation. The levels of phosphorus showed a range of variation, with (F3) and (T3) demonstrating P levels of 51.9 and 22.2 mg/kg, respectively (Table 3). The varying levels of phosphorus may be influenced by land uses or applications of fertilizers. According to Annappa *et al*. (2024), changes in land use can impact the dynamics of phosphorus in soils, leading to changes in its availability and distribution.

However, it is important to note that low levels of P were observed in G1 (6.16 mg/kg) and F1 (6.33 mg/kg) (Table 3), which can have implications for crop yields, with reports suggesting reductions of up to 55% in certain regions (Kvakić *et al*., 2018). According to FAO (1979) indicators and criteria for land degradation assessment, phosphorus was slightly degraded (SD) in most study sites except F1, G1, T1, and G2, T2 soils, which were highly and moderately degraded, respectively. Phosphorus is widely recognized as being one of the elements that limits plant growth and crop production on a scale. Its deficiency can have pronounced effects, posing significant losses to farmers if not supplied adequately (Abosede *et al*., (2015). Potassium levels were found to be high (1.75 cmol/kg) (Table 3) in (G1), indicating a potential source of manure deposition from livestock. Byrnes *et al*. (2018) found that continuous grazing has the potential to cause soil compaction and decrease the overall health of the soil, leading to potential effects on potassium dynamics. On the other hand, rotational grazing has been proven to enhance soil organic carbon levels and potentially improve potassium availability. Degradation with regard to potassium (K^+) was slightly degraded (SD) in all locations. Notably, high exchangeable sodium percentage (ESP) values were noted in (G3, 31%) and (F2, 22.1%), suggesting concerns related to sodicity that can have detrimental effects on soil structure. Elevated levels of sodicity have the potential to impact nutrient balance, leading to deficiencies or toxicities that can have adverse effects on both plant growth and crop productivity (Osman, 2018; Roy & Chowdhury, 2020). It's worth noting that, except for the high degradation in G3, all other locations exhibited moderate degradation (MD) or even slight degradation (SD), as in the cases of (F2) and (G1), respectively.

The organic matter degradation was more pronounced when compared to the other parameters for physical and chemical degradation in all the sites that were investigated. Very high degradation (VHD) was observed in most farmland and tree plantation sites, with the exceptions of G1, G2, and T2, where it was classified as highly degraded (Table 4). Tree plantations play a role in increasing carbon (SOC) in the soil through the accumulation of leaf litter fall, which enhances both nutrient availability and organic matter (Bhardwaj *et al*., 2022). A study on plantations by Zhong *et al*. (2022) found that SOC levels significantly increased, indicating that tree cover promotes matter accumulation in degraded soils. The organic matter (OM) content values for all locations (as shown in Table 3) were low, suggesting OM degradation according to FAO (1979) indicators and criteria for land degradation assessment. This decrease in OM may be attributed to crop uptake intensified by continuous cropping without adequate measures for nutrient replacement, such as the use of fertilizers or other forms of soil conservation practices (Abosede *et al*., 2015). The results from analyzing base saturation indicate that there is evidence of soil degradation (VHD) across all the sites, regardless of land-use type. This consistent pattern suggests that base cations have been depleted due to practices such as intensive agriculture, overgrazing, or inadequate soil management. According to Musa *et al*. (2024), it is reported that farming methods like monoculture and suboptimal soil management contribute to accelerated soil erosion and mineral depletion, which leads to removal of essential nutrients that outpaces replenishment, resulting in further reduction of base cations and compromising soil fertility over time.

Table 3. Soil quality indicators for land degradation assessment under different land uses

Land Uses	Bulk Density (gcm^{-3})	BS (%)	N (%)	P (mg/kg)	K (cmol/kg)	ESP (%)	EC (ds/m)	OM (%)
F1	1.3	0.85	0.14	6.33	0.42	9.93	0.38	0.58
F2	1.6	0.85	0.1	29.9	0.33	22.1	0.14	0.95
F3	1.4	0.91	0.12	51.9	0.78	16.4	0.46	0.81
G1	1.4	0.86	0.15	6.16	1.75	8.7	0.95	1.78
G2	1.4	0.92	0.14	7.41	1.11	18	0.18	1.68
G3	1.6	0.93	0.14	9.27	0.84	31	0.46	0.91
T1	1.4	0.86	0.11	6.6	0.43	13.2	0.82	0.79
T2	1.7	0.89	0.18	7.3	0.61	11.7	0.12	1.91
T3	1.6	0.83	0.19	22.2	0.57	21.4	0.18	0.87

Key: F1: Farmland 1st location, F2: Farmland 2nd location, F3: Farmland 3rd location, G1: Grazing land 1st location, G2: Grazing land 2nd location, G3: Grazing land 3rd location, T1: Tree plantation 1st location, T2: Tree plantation 2nd location, T3: Tree plantation 3rd location.

Table 4. Degradation Levels of Individual Soil Quality Indicators across Land Uses

Land Uses	Bulk Density (gcm^{-3})	BS (%)	N (%)	P (mg/kg)	K (cmol/kg)	ESP (%)	EC (ds/m)	OM (%)
F1	SD	VHD	SD	HD	SD	SD	SD	VHD
F2	MD	VHD	MD	SD	SD	MD	SD	VHD
F3	SD	VHD	MD	SD	SD	MD	SD	VHD
G1	SD	VHD	SD	HD	SD	SD	SD	HD
G2	SD	VHD	SD	MD	SD	MD	SD	HD
G3	MD	VHD	SD	SD	SD	HD	SD	VHD
T1	SD	VHD	MD	HD	SD	MD	SD	VHD
T2	MD	VHD	SD	MD	SD	MD	SD	HD
T3	MD	VHD	SD	SD	SD	MD	SD	VHD

Key: VHD: Very highly degraded, HD: Highly degraded, MD: Moderately degraded, SD: Non-slightly degraded, F1: Farmland 1st location, F2: Farmland 2nd location, F3: Farmland 3rd location, G1: Grazing land 1st location, G2: Grazing land 2nd location, G3: Grazing land 3rd location, T1: Tree plantation 1st location, T2: Tree plantation 2nd location, T3: Tree plantation 3rd location.

CONCLUSION AND RECOMMENDATIONS

From the findings of this study, it is clear that soil compaction, which can originate from various activities such as livestock trampling and massive un-recommended agricultural practices which reduce soil nutrients, is a significant factor contributing to land degradation. It was found that tree plantations and grazing lands had higher bulk density levels, suggesting soil compaction. The majority of soils in the areas examined for this study possess textures (>85% sand), leading to poor retention of nutrients and moisture. However, some farmlands showed loamy sand textures with improved silt content, leading to enhanced availability of nutrients. Nitrogen and phosphorus deficiencies ($N \leq 0.12\%$ at 4 sites; $P \leq 7.41$ mg kg^{-1} at 5 sites) and sodicity risks ($ESP > 15\%$ at 5 sites) were identified as issues during the assessment. Organic matter content was most severe, with ≤ 1.91% (classifying 6/9 sites as "very highly degraded") and critically low base saturation (≤0.93%), indicating unsustainable nutrient cycling. According to the FAO (1979) indicators and criteria for land degradation assessment, varying degrees of degradation in the soil quality of farmland and tree plantations were observed, specifically issues related to nitrogen and phosphorus levels, indicating potential over-exploitation without sufficient fertilization practices. Furthermore, there were some areas where grazing and farmland raised issues regarding levels of sodium, which could potentially lead to problems with sodicity that would negatively impact crop growth by affecting soil structure. Moreover, it became clear during our investigation that many locations within the study area were experiencing depletion in organic matter content along with base saturation, indicating very high degradation caused by unsustainable land management practices. Based on the findings of the study, the following recommendations were made:

1. Farmers should adopt the use of recommended techniques during their agricultural activities.
2. Practice of the use of organic amendments (compost, manure, and crop residues) should be encouraged among farmers in order to improve organic matter and nutrient cycling.
3. Apply soil amendments like gypsum ($CaSO_4$), calcium compounds, or other soil amendments to mitigate the effects of sodicity and improve soil structure.
4. Farmers should adopt the minimum tillage in order to provide more aeration and prevent further compaction.
5. Governments should provide sufficient extension agents to educate farmers on agricultural practices and provide incentives (subsidies, grants) for adopting soil conservation measures.

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