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Full Length Research

Soil degradation assessment of some selected land use in two Agro ecological zones of Gombe State, Nigeria

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ABSTRACT: Soil degradation remains a global environmental phenomenon caused by anthropogenic activities. The assessment of degradation status of soils in some selected land uses of two agro ecological zones of Gombe state was carried out. Representative soil samples from four land uses were collected from 0 - 30 cm depths (cultivated, Fadama, forest and mining land). The soil samples were labeled, air-dried, crushed, sieved through a 2 mm mesh, and subjected to various physical and chemical analyses. Data collected were subjected to descriptive statistics and soil degradation assessment was done following standard procedures. The levels of degradation of soils were assessed using the standard indicators and criteria for land degradation assessment by the Global Assessment of Land Degradation. Analytical data from each sample were placed in a degradation class by matching the soil characteristics with the land degradation indicators, while estimation of the overall degree of degradation was arrived at mathematically, using physical, chemical, and biological parameters. The results shows that the textural class of the soil ranged from clay to sandy loam. Permeability ranged from 0.10 to 7.97 cm hr^{-1} corresponding low to high permeability. Bulk density ranged from 1.24 to 1.62 g cm^{-3}. Organic matter was very low in all the study sites. Available phosphorus ranged from 6.2 to 15.5 $mgkg^{-1}$. Total nitrogen was predominantly low (0.05 – 0.08%) in all the land uses. Exchangeable Sodium Percentage (ESP) of the sites depicted that most of the soils were non sodic soils (0.71 – 1.61%). The potential for all the land uses are moderately degraded varied from Fadama land (41.67%), cultivated land (44.44%), mining land (47.22%) and forest land (50%), respectively. The major barriers in the study areas were low fertility, and soil conservation measures. In order to optimize crop production in these areas, there may be need to introduce soil conservation measures. The practice may include use of farm yard manure, compost, crop residues, green manure or poultry manure to boost soil fertility. Regular monitoring of the fertility status of the soils is encouraged.

Keywords: Agro ecological zones, soil degradation, soil fertility; sustainability, indicator.

INTRODUCTION

Soil degradation remains a global environmental phenomenon that is interpreted differently in different environments (Mohammed *et al.,* 2019). Soil degradation literally refers to the impairment of natural quality of soil component of any ecosystem (Awwal *et al.,* 2020). It depends not only on the interaction of different physical, chemical, and biological factors of soil, including soil properties, topography, and climatic characteristics (Brevik *et al*., 2015); but also on land use, anthropogenic factors, and management (Cerdà *et al*., 2016). However, Khaledian *et al.* (2017) define soil degradation as the decline in soil quality, which encompasses physical, chemical, and biological deterioration, caused by anthropogenic activities. Such soils have their natural potentials threatened, there by its protection and rehabilitation is absolutely indispensable and inevitable. It is seen as the loss of land productivity, quantitatively and qualitatively, as a result of many processes, such as soil erosion, overgrazing, cultivation, and cropping, leaching, water logging and pollution. Soil scientists categorize soil degradation processes, or mechanisms as either biological, chemical or physical. Chemical indicators refer to nutrient cycling, water relations and buffering and include: acidification, leaching, salinization, loss of organic matter, loss of nutrients, pesticide accumulation, and accumulation of toxic elements (Nael *et al*., 2004; Ahukaemere *et al.* 2012). Biological indicators of soil quality include plant and animal species that play a key role in supporting critical soil functions and hence ecosystem services and include: a reduction in the total biomass carbon and a decline in soil biodiversity (Barrios, 2007; Adhikari *et al.,* 2016; Lal, 2013). Physical indicators are related to the arrangement of solid particles and pores involved in soil hydraulic flows and include aggregate stability, bulk density, infiltration, compaction, erosion, desertification, anaerobism, environmental pollution, and unsustainable use of natural resources (Ewetola *et al.,* 2015; Schloter *et al*., 2003; Yusuf *et al.,* 2015). Kuria *et al.* (2019) deduced that, soil degradation is a major threat to food security, particularly in the context of a rapidly growing global population living on finite land resources. Land degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation (Molchanov *et al.,* 2015). Millions of hectares of land per year are being degraded in all climatic regions (FAO *et al.,* 2017). About 60% of the deforestation in the developing world may be attributable to the advance of agricultural practices, about 20% to logging operations (including mining) and 20% to household use of fuel wood (Gorobtsova *et al.,* 2016).

About 15% of the global seven billion people alive today are classified as food insecure (FAO *et al*., 2017). Although, with the global population projected to hit nine billion by 2050 (Montpellier, 2013), the food insecurity challenge can be expected to increased, especially for sub-Sahara Africa (Bremner, 2012). Contemporary strives to meet food and livelihood needs of sub-Saharan smallholder farms have often led to severe soil degradation. Ewetola *et al.* (2015) opined that environmental degradation caused by inappropriate land use is a worldwide problem that has attracted attention in sustainable agricultural production systems. Study conducted by Di *et al.* (2013) revealed that agricultural management practices have significant influence on soil quality which in turn is essentially linked to the sustainability of agro ecosystem functions and productivity. Therefore, for a successful agricultural production requires the sustainable use of soil resources as soil loses its quality and quantity within a short period of time (Kiflu and Beyene, 2013). Many studies have addressed effects of land-use changes and land management on soil properties.

However, anthropogenic reductions in soil health, and its components, are a pressing ecological concern (Doran and Zeiss, 2000). Detection of changes in these components could provide vital information on soil health and could assist in proffering management practices for its improvement. This research aimed to assess the degree of degradation of soils in selected land uses in the study area using some soil quality indicators and criteria for soil degradation assessment and suggest modest recommendations for the sustainable use of the soil in the future.

MATERIALS AND METHODS

The study was carried out in two agro-ecological zones (Northern and Southern Guinea Savannah) of Gombe State, Nigeria on four land uses (cultivated, Fadama, forest and Mining lands); which is located between latitude 9°18' to 10°16'N and longitudes 10°57' to 11°18'E with elevation ranging from 336 to 564 meters above sea level (Ibrahim *et al.,* 2021a, b) (Figures 1 and 2). The average annual temperature varied between 30 and 32°C and an annual rainfall in the study area varied from 850 to 1200 mm (Ibrahim *et al.,* 2022a, b). The soil of the study area fell within the Leptosols, Cambisols and Luvisols from Limestone and Shale of the Pindiga formation. It is deep, whitish, clay loam and free from concretions and stones (Ibrahim *et al.,* 2021b*).* The economic activities of local communities of the study area are mixed farming systems (maize, millet, sorghum, rice, millet, cowpea, soybeans, groundnuts, Bambara nut, and vegetables crops etc.) that involve arable crops and animal production (Ibrahim *et al*. 2021b).

Soil sampling and laboratory analyses

Two composite samples for disturbed soils and soil cores were collected for the measurement of permeability (Ks) (cm hr.) and the bulk density (BD) (g cm^{-3}) were randomly collected at 0 - 30 cm depth using a soil auger in all the four land uses respectively. The soil samples were labelled, air-dried, crushed, sieved through a 2 mm mesh, and subjected to physical and chemical analyses. Particle size analysis was determined using the Bouyoucos hydrometer method (Brady and Weil, 2017). The cylinder cores were linked to a Mariotte's bottle to measure the Ks using the constant head method based on Darcy's law. Subsequently, the BD were determined from the same soil core samples (Fasinmirin and Adesigbin, 2011). Soil pH was measured in a 1:2.5 soil-water ratio suspension while electrical conductivity (EC) was determined using a conductivity meter in a soil-water extract method (Rowell, 1994). Organic carbon was determined by the wet digestion method as described by Walkley and Black (1934) and the content of organic matter was obtained by multiplying organic carbon content by a factor of 1.724. Micro-Kjeldahl digestion, distillation and titration method

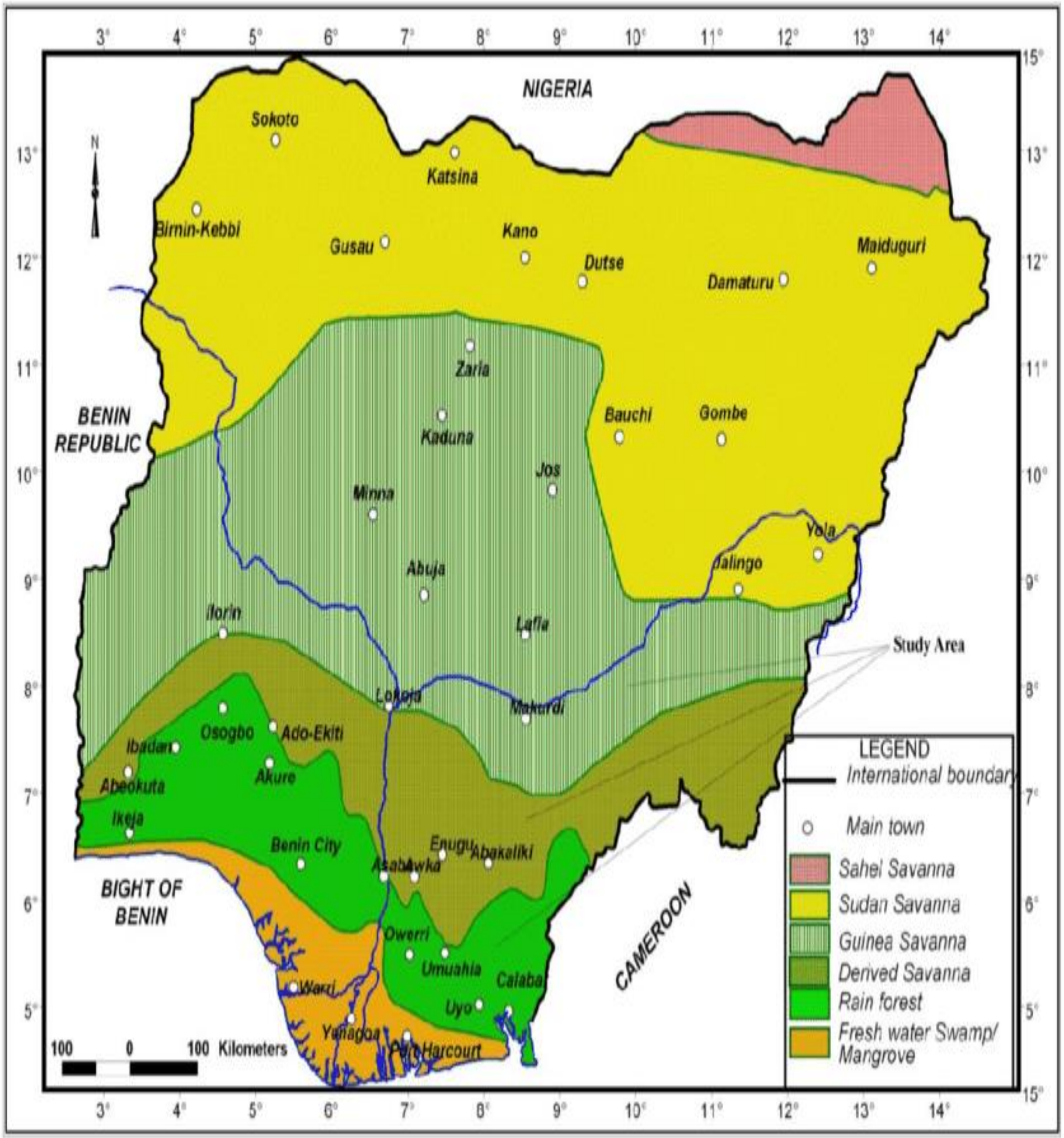

Figure 1. Map of Nigeria showing Agro ecological zones (**Sources:** Hakeem *et al.,* 2020).

was used to determine total nitrogen as described by Akinremi *et al.* (2003). Available phosphorous was analyzed using Bray 1 method using 0.03 M NH4F and 0.10 M HCl solution according to Bartlett *et al*. (1994). Cation exchange capacity (CEC) and exchangeable Ca, Mg and K were extracted with 1 M NH4OAc at pH 7 by which exchangeable Ca and Mg in extracts were analyzed using atomic absorption spectrophotometer, while K by flame photometer (Agbenin, 1995), base saturation percentage (BSP) and exchangeable sodium potential were duly computed. Exchangeable cations (Ca, Mg, K, Na) were determined by the NH_4oAC method as described by Agbenin (1995). Cation exchange capacity (CEC) was determined by the NH_4oAC extraction method of Rhoades (1982), base saturation percentage (BSP) and exchange-able sodium potential were duly computed.

Soil degradation assessment

Soil degradation was assessed using the standard indicators and criteria for land degradation assessment

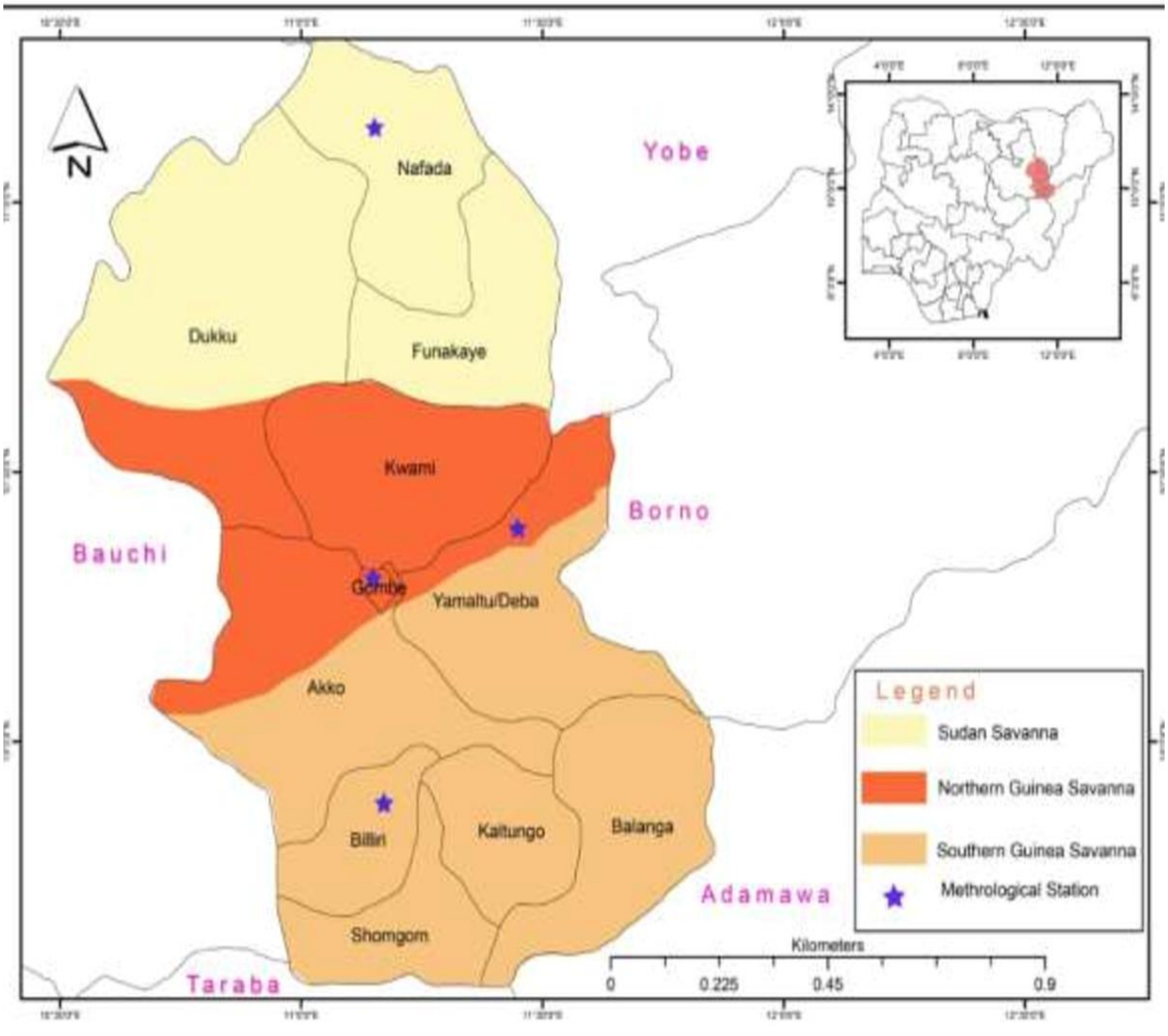

Figure 2. Map of Gombe State showing the Agro ecological zones (**Source:** Bello *et al.,* 2020).

outlined by the Global Assessment of Land Degradation as indicated in Table 1a and b (GLASOD, 1998). Analytical data from each sample were placed in a degradation class by matching the soil characteristics with the land degradation indicators, while estimation of the overall degree of degradation (ODD) was arrived at mathematically, using physical, chemical, and biological parameters as shown in equation 1

$$\mathbf{O}\mathrm{DD} = \frac{(\sum \text{Degree of degradation of each quality})}{\text{ax. degree of degradation x Number of qualities}}\, x100$$

Statistical analysis

The data generated were subjected to descriptive statistics using Microsoft Excel version (2013). Mathematical estimation of the overall degree of degradation was carried out using the degradation equation with Microsoft Excel.

RESULTS AND DISCUSSION

Physical degradation

The results of soil physical and chemical properties obtained from the study are presented in Tables 2 and 3 while degradation scores for each indicator and overall degradation rating are shown in Table 4. Particle size distribution from different land use indicated different textural classes. Although textural classes are one of the intensive properties of the soil that is not easily affected by management practices or land use, which are rather permanent and often used to characterise the soil's

Table 1a. Indicators and criteria for land degradation assessment.

Indicator	Degree of degradation			
	1	2	3	4
Physical degradation				
Soil bulk density(mgm^{-3})	<1.5	1.5 - 2.5	2.5 -5	>5
Permeability (cm hr^{-1})	<1.25	1.25 – 5	5 – 10	>20
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 (increaseby1%ofCEC)	<10	10 – 25	25 – 50	>50
Base saturation (decrease of Saturation in more than 50%	<2.5	2.5 – 5	5 – 10	>10
Excess salt (Salinization) (increase of conductivity mmho cm^{-1}yr^{-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), GLASOD, (1998); Snakin et al. (1996).

Table 1b. Class of degradation.

Class of degradation	Overall degree of degradation (%)	Description
1	0 -25	None to slightly degraded
2	26 – 50	Moderately degraded
3	56 – 75	Highly degraded
4	76 – 100	Very Highly degraded

The value of 1 shows minimal degradation while 4 represents an extreme range of degradation.

Table 2. Particle size distribution of soils of the study area.

Land use	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Texture
Cultivated land	660	200	130	Sandy loam
Mining area	660	120	220	Sandy clay loam
Forest land	850	70	80	Loamy sand
Fadama land	350	180	470	Clay

physical make-up (Agbai and Kosuowei, 2022). The soils in the Fadama land had higher Clay content compared with the cultivated land (Table 2). This is in line with the observation of Ibrahim *et al.* (2021b) who deduced that clay-rich Fadama land has been continually affected by problems of inadequate aeration, waterlogging, increased run off as well as erosion, and workability problems during dry and very wet periods. The texture of the soil has a high influence on the physical and chemical properties of the soil which are used as a quality indicator for soil quality assessment. An average bulk density of 1.24 and 1.47 mgm^{-3} (<1.5 mgm^{-3}) was obtained from the forest and cultivated land of the study area and this ranged from none to slightly degraded concerning bulk density, while mining and Fadama land with an average value of 1.52 and 1.63 mgm^{-3} (1.5 - 2.5 mgm^{-3}) were moderately degraded. It is however worthy of note that the bulk densities of the four land use (both the cultivated, mining, forest and Fadama land) were less than the critical limits for root restriction (1.75 – 1.85 g/cm^{-3}) as reported by soil survey staff (1996). The loss of SOM by the conversion of the forest into cultivated fields probably caused a higher bulk density in the cultivated soils (Ibrahim *et al.,* 2021b). According to Awwal *et al,* (2020), the bulk density of soil affects compaction, root growth, and water retention within the soil, while Schoenholtz *et al.* (2000) opined that changes in bulk density affect other properties and processes that influence water and oxygen supply. However, Brady and

Table 3. Soil Quality (QI) Indicators for soil degradation assessment.

Land use	Bulk density (mgm^{-3})	Permeability ($cmhr^{-1}$)	Total nitrogen (%)	Available phosphorus ($mgkg^{-1}$)	Exch. K (Cmol (+) kg^{-1})	ESP (%)	EC (dSm^{-1})	Percent base saturation (%)	Organic matter (%)
Cultivated land	1.47	2.03	0.05	10.0	1.81	0.97	0.38	60.6	0.95
Mining area	1.52	1.65	0.06	6.90	1.32	0.91	1.42	60.5	1.00
Forest land	1.24	7.97	0.08	6.20	0.42	1.61	0.40	60.4	1.81
Fadama land	1.62	0.10	0.06	15.5	1.67	0.71	1.05	60.6	1.10

Table 4. Degradation scores for the various studied soils.

Indicators	Cultivated land	Mining land	Forest land	Fadama land
Physical Degradation				
Soil bulk density (mgm^{-3})	1.00	1.00	1.00	2.00
Permeability ($cm\ hr^{-1}$)	2.00	2.00	3.00	1.00
Chemical Degradation				
Content of N element (multiple decreases) N (%)	4.00	4.00	4.00	4.00
Content of Phosphorus Element ($mg\ kg^{-1}$)	1.00	3.00	3.00	1.00
Content of Potassium Element (Cmol (+) kg^{-1})	1.00	1.00	1.00	1.00
Content of ESP (increase by1% of CEC)	1.00	1.00	1.00	1.00
Base saturation (decrease of Saturation in more than 50%	1.00	1.00	1.00	1.00
Excess salt (Salinization) (increase of conductivity mmho $cm^{-1}yr^{-1}$)	1.00	1.00	1.00	1.00
Biological Degradation				
Content of humus in soil (%)	4.00	3.00	3.00	3.00
Overall Degradation Index	44.44%	47.22%	50.0%	41.67%

Weil (2017) linked bulk density to soil texture, structure, and organic components. Oyedele *et al.* (2009) opined that cultivation has been noted to increase bulk density. Fadama land was none to slightly degraded soils compared to cultivated and mining land which were moderately degraded in terms of permeability, while forest land was highly degraded concerning the degradation scores as shown in Table 3. This meant that Fadama land may retain more moisture than cultivated and mining land. Awwal *et al.* (2020) indicated that there is an inherent relationship between bulk density and permeability (K_s). The permeability of soils is also affected by soil texture, structure, and porosity.

Chemical degradation

The result of the chemical degradation of the soils is presented in Table 3. The percentage of the nitrogen content of the soils was very highly degraded situations in all the land uses. The content of nitrogen as shown in Table 3 indicates a low availability of Nitrogen as per the Esu (1991) rating scale. This might be a reflection of the soil amendment strategies employed by farmers. Generally, the low nitrogen content recorded in this study might be due to the high rate of nitrogen (N) mineralization and loss of organic matter content in the soils (Senjobi and Ogunkunle, 2011). The use of organic mulches and proper management practices such as discouraging the removal of crop residues (stubbles) by farmers should be employed to manage the rate of nitrogen degradation and loss in these soils (Ewetola *et al.,* 2015). Nitrogen is a key nutrient element in soil quality indicators and is a basic component of many physiological processes in plants (Ananya *et al.,* 2019; Ibrahim *et al* 2018). Agbede (2009) reported that Nitrogen (N) is the most important constituent element needed for plant growth, development and reproduction. Ewetola *et al.* (2015) and Ibrahim *et al.* (2022) opined that N is the most limiting nutrient element especially, in the tropics where organic matter decomposition is rapid and nitrogen released from the process is easily lost through leaching or evaporation. Fadama and cultivated soils were highly degraded while forest and mining lands were none to slightly degraded soils concerning the content of phosphorus. The generally low values of available phosphorus in the soils indicated the need for the application of phosphorus to the soils for optimum crop production. Conversely, all four land uses were none to slightly degraded soils concerning the content of potassium element and values were greater than 0.16 (Cmol (+) kg^{-1}), exchangeable sodium percentage (ESP), base saturation percentage (BSP), and electrical conductivity (EC). Amongst others, this is a good indication that the soils had none to very slight salinity and sodicity threat. The degradation indices ranged from 44.44 % for ESP, BSP and EC for cultivated land, 47.22 % for ESP, BSP and EC for mining land to 50.0. % for ESP, BSP and EC for forest land and 41.67 % for ESP, BSP and EC for continuously cultivated fadama land respectively.

Biological degradation

In terms of humus content of the soils, Fadama, forest and mining land soils were highly degraded, where values fell below 2.0% while cultivated soils were very highly degraded (<1.0%) (Table 3). This is an indication of very high biological degradation which is typical of savanna soil. Very low organic matter (OM) recorded in this study is indicative of very high biological degradation of all the soils of the study areas. The results obtained corroborate the findings of Stevenson and Cole (1999) who deduce that cultivation of natural land resources induces SOM losses, which in turn directly affects the soil's chemical, physical, and biological properties, finally resulting in loss of crop production capacity. The OM depletion might be due to crop uptake exacerbated by continuous cropping without adequate measures for nutrient replacement either through the use of inorganic fertilizer or other forms of soil conservation measures. Degradation and low humus content in savanna soils have been reported by several researchers (Raji *et al.,* 1995; Odunze, 1998; Ibrahim *et al.,* 2010; Ibrahim and Umar, 2012; Maniyunda, 2012). However, the loss rate of humus is noted to be higher in cultivated soils than Fadama, forest and mining land soils. Ashenafi *et al.* (2010) attributed the higher loss of humus in cultivated soils to the fact that cultivation accelerates the depletion of organic matter content in soils. Land use practices such as bush burning which is very rampant in the savanna ecosystem might be partly accounted for the destruction of OM content and even the microbial populace in the soils. To protect these soils from further biological degradation, conservation tillage and proper management of organic wastes should be employed (Awwal *et al.,* 2020).

Overall degradation

The results of the overall degradation rate of the soils are presented in Table 3. The overall degradation rate indicates that all four land uses soils were moderately degraded (Fadama land 41.67%, cultivated land 44.44%, mining land 47.22% and forest land 50.0%). This corroborates earlier reports that over cultivation may lead to the depletion of soil qualities (Oyedele et *al.* 2009; Ande and Senjobi, 2014).

Conclusion and Recommendation

An investigation into soil degradation was conducted in the 2020 planting season to assess the degree of degradation of the soils in some selected land uses of two agro-ecological zones of Gombe State. The study revealed that most of the soils (about 50%) were moderately degraded, even though, those of the forest land that would have been expected to be better are showing signs of serious degradation. Base on the findings of this study, the following recommendations were proposed.

1. Application of inorganic fertilizer to improve the nitrogen, phosphorous and potassium content of the soils should be encouraged.
2. The use of organic manure such as the incorporation of legumes (as green manure), farmyard manure, and compost and poultry droppings should be encouraged to improve the productivity of these degraded soils.
3. Bush following as well as other management practices such as mulching will go a long way to replenish the organic matter and nutrient status of the soils.
4. Proper monitoring of the fertility status of the soils should be encouraged.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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