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ANALYSIS OF PHYSICO-CHEMICAL PARAMETERS OF SOILS AS DETERMINANTS OF SOIL DEGRADATION IN ZARIA, NIGERIA

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ABSTRACT

This study aimed to evaluate soil degradation in specific farmlands near Zaria, Kaduna State, Nigeria. Data collection methods included conducting field surveys and analyzing soil samples in the laboratory for physico-chemical parameters. Soil samples were collected at a depth of 0-15 cm from five different farmlands in four wards of Zaria, resulting in a total of twenty samples. The samples were analyzed using Atomic Absorption Spectrophotometry to evaluate their physical and chemical properties. Principal Component Analysis and Pearson correlation were used for statistical analysis. Component 1 explains 30.8% of soil degradation, component 2 explains 25.6%, component 3 explains 14.5%, and component 4 explains 11.4%, totaling 82.2% of the variance explained by these four components. A factor loading greater than 0.75 is chosen as the parameter that most impacts land degradation in this study. Thus, in PC1, parameters of Bulk density (0.963), Porosity (-0.954), GMC (-0.287), Organic carbon (-0.77) and CEC (0.29) have strong effects on land degradation. PC2 explains CEC (0.753), Na (-0.513) and K (-0.88) to have effect on land degradation. PC3 explains parameters of Organic carbon (0.391), CEC (-0.221) and Na (0.205) to have strong impact on land degradation. While Organic carbon (0.822), CEC (0.395), Na (-0.178) and K (-0.149) have strong impacts on land degradation in PC4. The study indicates most soils of the study area were degraded. The study recommends that knowledge on the use of fertilizers to be effectively communicated to farmers in order to caution excess use and avoid future occurrence of soil degradation.

Keywords: Soil Degradation, Physico-Chemical Parameters, Farmland, Zaria

INTRODUCTION

Land degradation is an essential part of environmental change process that results in loss of valuable land resources. It additionally indicates a reduction in the resource potential of a land through the activities of some processes that may force the condition of the land to become unpleasant and less valuable to man. Such processes include water erosion, wind erosion, flood hazard, drought and desertification, deforestation, loss of essential mineral nutrients for plants leading to reduction in vegetation cover, pollution, and permanent inundation of land among others (Dregne, 1986). These processes cause dilapidation of ecosystem, services, reduction in ecosystem stability, reduction in biological efficiency potential, decline in the ability of land to support human population and biodiversity. However, land degradation becomes a threat when it directly or indirectly impacts habitation livelihood and survival of people. Degraded lands are more prone to the adverse effects of climatic change such as increased temperature and more severe droughts (Adewuyi, 2008).

Soil degradation refers to the deterioration in soil's inherent capability to perform environmental and socio-economic functions. Soil degradation is also a loss of soil function. It is a serious and most common system of land degradation because the soil is the source for production (Blum, 1998). It encompasses physical, chemical and biological deterioration. A soil degraded if the loss of basic qualities which manifests in reduced produce is permanent (Mbagwu, 2003).

Soils affect food safety directly since it supports agriculture. Agriculture yields the food we eat and make available the main source of livelihood for 36% of the world's total work force (ILO, 2007). Agriculture and the food we eat is hinge on soil. Under appropriate management, soils are a considerably renewable resource, while under unsuitable management they are effectively a very finite resource. Under natural state it can take 500-1,000 years to form an inch of soil from parent rock.

Soil is an essential resource for the future of humanity. It needs to be secured and improved. Instead, more than half (52%) of all productive food-producing soils globally is now categorized as degraded, many of them severely degraded (UNCCD, 2015). All through human history, at least twelve past civilisations have bloomed on fertile soils and made enormous advances but only to disappear over time as their soils gradually degraded and could no longer feed their populations. Soil degradation is a serious and increasing global problem, with consequences for a number of key policy areas, including food security, climate change, flood risk management, drought tolerance, and drinking water quality, agricultural resilience in the face of new crop diseases, biodiversity and future genetic resources.

A study by Junge (2010) revealed that severe use of agricultural land often led to reduction of organic matter and nutrients in soil which promote decrease in crop production. Land degradations as a result of deforestation, loss of top soil, loss of vegetation, soil nutrient depletion, leaching, soil compaction, soil crusting, water logging, flooding, and land pollution all together have resulting impact on the current socio-economic livelihood of farmers in Zaria. Such impact is seen in poor crop yield due to soil erosion and loss of soil nutrient (Idoko, 2004) flooding due to poor building of structures along water ways, pollution of water bodies by strong effluents from industries and farm lands (Niemeijer & Mazzucato, 2002). The purpose of this study is to ascertain the physio-chemical characteristics of soil over the selected farmlands around Zaria area.

The need to comprehend the dynamics of soil degradation in terms of the physio-chemical parameters cannot be overstressed. Hence, precise and relevant assessment methods of soil degradation in the study area with a flexible scale combining socio-economic, institutional, and biophysical aspects and driving forces are required to plan actions and investments to reverse land degradation, improve socio-economic livelihoods, and preserve dry land ecosystems and its unique biological diversity (Snel *&* Bot, 2003).

MATERIALS AND METHODS

Study Area

Zaria lies on the vast and high heaving plains of Northern Nigeria which is likewise known as the High plains of Hausa land. Zaria is located eighty-three (83) kilometres North of Kaduna State. It is located within latitude $11^{0}40'$ to $11^{0}06'$North and longitudes $7^{0}36'$ to $7^{0}40'$East (Fig.1). Zaria is located on a height of about 670 m above sea level. The early history of Zaria (Zazzau) is one of the seven Hausa Kingdoms (Hausa Bakwai). The core of the kingdom was surrounded by rock outcrops rising abruptly some hundred meters above the country side (Urqhuart, 1977) and (Idris, 2004) and rendered secured by high city walls together with gates (Kofa).

Zaria soils are categorised as leached ferruginous tropical soils developed on weathered regolith overlain by a thin deposit of wind-blown silt from the Sahara Desert during many decades of propagation of the tropical continental air mass into the area (McCurry, 1970). Most of the soils have a sandy loam texture (Jaiyebo, 1995). Leaching of clay materials and ions down the soil profiles is the main soil development process. The soil shows a marked horizon difference with iron oxide deposits in the clay-rich B-horizon, underlying the A-horizon in forms of mottles, concretions or ferruginous hard pans called duricrusts (Klikenberg, 1970). The top soil is rather coarse due to eluviation of the fines of the A-horizon (Jaiyeoba & Ologe, 1990).

Agriculture had been the primary economic activity of the people of Zaria since the beginning of the settlement. All other economic activities were hence secondary to agriculture. This was due to the wide agricultural practice by all classes of *Zazzagawa* irrespective of their social and economic standing in the society. Agriculture was thus, the main provider of the society's food necessities as well as the major sources of raw material such as cotton, indigo, sugarcane, groundnut for industrial productions both within and around several parts of the area (Ikime, 1980).

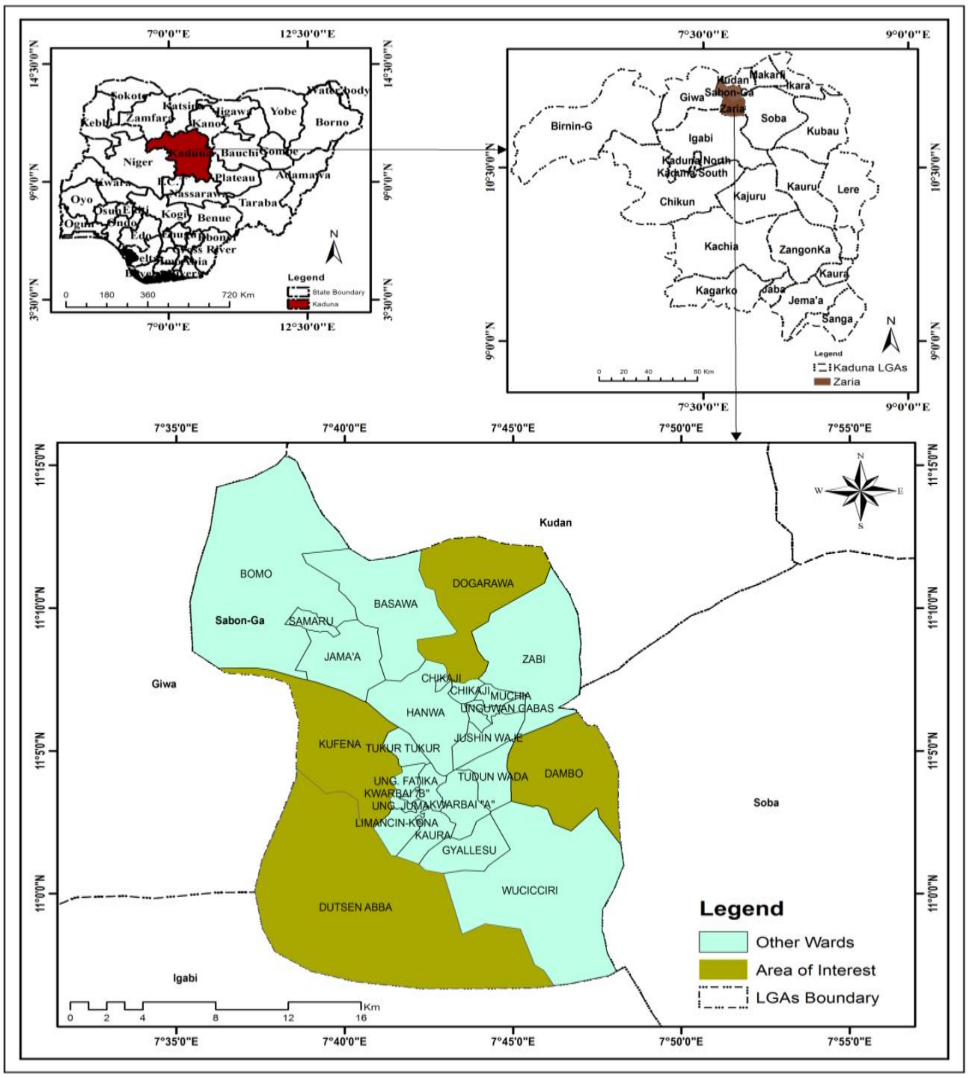

Figure 1: Map of the Study Area (Source: UJ Haruna2019)
Source: Adapted from Administrative Map of Kaduna State

Methods

Twenty (20) soil samples were purposively collected from four districts which are (Dutsen Abba, Dogarawa, Kufena, and Zabi). This selection was based on the criteria that the selected areas primarily in engaged in agricultural activities. In each district, soil samples were collected from five different farmlands. Forms of soil degradation analysed based on severity rank include soil fertility decline > compaction > gully > water logging > rill > leaching and pedestal.

The physical and chemical properties of soil analysed were (particle size distribution, bulk density, porosity, soil moisture, CEC, organic matter content, soil pH and exchangeable bases and base saturation). The study employed checklists and questionnaire administration while the soil analysis was carried out using Atomic Absorption Spectrophotometric meter.

To determine the severity of soil degradation in the study area, the soil physico-chemical properties were compared to soil fertility ratings for tropical soils which are summarised in Table 1.

Table 1: Rating for Interpreting Soil Physio-Chemical Properties

Soil Properties	Favourable	Unfavourable
Bulk Density	1.0 -1.5g/cm^3	> 1.5g/cm^3
Porosity	>50% in top 30cm	<40%
pH	Generally, 5.6-6.5	<4.5
	5.0 – 8.0 but varies with crop	>8.5
Organic carbon	>6	≤ 2
CEC (mg/L)	> 25 cmol/kg^{-1}	≤ 6 cmol/kg^{-1}
Na	>0.3	≤ 0.1
K	>0.3	≤ 0.15
Ca	>5	≤ 2
Mg	>1	≤ 0.3

Source: (Malagwi, 2007; Soil Survey Staff, 1975; Landon, 1991)

RESULTS AND DISCUSSIONS

Analysis of Physico-Chemical Parameters of Soils

Table 2: Analysis result for Bulk density, Porosity and Ground Moisture Content (GMC)

Parameters	Analysis	Dutsen-Abba	Zabi	Kufena	Zabi
Bulk Density (g/cm^3)	Mean	1.39	1.62	1.07	1.15
	Std. Dev	0.03	0.02	0.02	0.03
	COV	2.16%	1.24%	1.87%	2.61%
	ANOVA (F-ratio)		493.96		
	Sig.-Value		0.000		
Porosity (%)	Mean	47.55	38.9	59.6	56.6
	Std. Dev	0.55	0.57	2.06	1.97
	COV	1.16%	1.47%	3.46%	3.48%
	ANOVA (F-ratio)		200.98		
	Sig.-Value		0.000		
GMC (%)	Mean	1.08	1.10	1.10	1.12
	Std. Dev	0.04	0.02	0.04	0.05
	COV	3.70%	1.82%	3.64%	4.64%
	ANOVA (F-ratio)		0.867		
	Sig.-Value		0.478		

Source: (Author, 2019)

Table 3: Analysis Result for Organic Carbon and pH

Parameters	Analysis	Dutsen-Abba	Zabi	Kufena	Zabi
Organic Carbon (g/kg^{-1})	Mean	1.28	1.55	1.40	1.03
	Std. Dev	1.05	0.96	1.59	1.20
	COV	24.53%	21.10%%	36.14%	27.15%
	ANOVA (F-ratio)		0.039		
	Sig.-Value		0.989		
pH	Mean	7.89	8.43	7.62	8.63
	Std. Dev	1.45	0.56	0.96	1.05
	COV	18.37%	6.62%	12.60%	12.20%

	ANOVA (F-ratio)	0.986
	Sig.-Value	0.424

Source: (Author, 2019)

Table 4: Analysis Result for Cation exchange capacity (CEC), Sodium, Potassium, Calcium and Magnesium

Parameters	Analysis	Dutsen-Abba	Zabi	Kufena	Zabi
Cation Exchange Capacity ($cmol/kg^{-1}$)	Mean	15.4	20.9	23.5	14.4
	Std. Dev	14.7	18.55	22.91	14.8
	COV	51.09%	94.13%	85.10%	73.84%
	ANOVA (F-ratio)		0.382		
	Sig.-Value		0.767		
Sodium (Na) ($cmol/kg^{-1}$)	Mean	0.98	0.69	0.25	0.13
	Std. Dev	1.49	1.03	1.91	1.57
	COV	81.95%	84.22%	65.86%	50.16%
	ANOVA (F-ratio)		2.220		
	Sig.-Value		0.125		
Potassium (K) ($cmol/kg^{-1}$)	Mean	0.89	0.48	0.39	0.62
	Std. Dev	0.07	0.09	0.04	0.01
	COV	39.19%	53.34%	16.86%	54.53%
	ANOVA (F-ratio)		0.997		
	Sig.-Value		0.420		
Calcium (Ca) ($cmol/kg^{-1}$)	Mean	8.12	2.56	7.30	6.35
	Std. Dev	5.55	7.23	8.41	3.84
	COV	30.63%	32.05%	48.61%	23.49%
	ANOVA (F-ratio)		0.896		
	Sig.-Value		0.465		
Magnesium (Mg) ($cmol/kg^{-1}$)	Mean	0.80	0.89	0.48	0.43
	Std. Dev	0.18	1.49	0.36	0.68
	COV	6.43%	36.43%	14.52%	48.98%
	ANOVA (F-ratio)		1.786		
	Sig.-Value		0.193		

Source: (Haruna, 2019)

Tables 2, 3 & 4 provide the analysis results of the physico-chemical parameters of soils. The result indicates soils within the study area have Bulk Densities within favorable limits (1.0 - 1.5g/cm^3) except for Zabi (1.62g/cm^3). Soil porosity analysis ranges from 59.6 % - 38.9% with highest mean in kufena soils (59.6%) while lowest in Zabi (38.9%). The mean moisture content ranges between 1.08 - 1.12%, with Dutsen-Abba having the least soil moisture (1.08%) and Zabi (1.12%) have the highest. The differences in the soil organic matter content amongst the farmlands by analysis of variance are statistically significant at the 0.05 level. The value is highest over Zabi (1.55g/kg^{-1}) and lowest in Zabi (1.03g/kg^{-1}). However, soil pH values in the study area ranges from 7.89 in Dutsen-Abba to 8.63 in Zabi. The result of CEC shows that soils in the four districts are within unfavorable limits (<25 cmol/kg^{-1}), with Kufena (23.5 cmol/kg^{-1}) having the highest and Zabi (14.4 cmol/kg^{-1}) having the least. Accordingly, the exchangeable bases of soils in the study area including Na (0.13 – 0.98 cmol/kg^{-1}), K (0.39 – 0.89 cmol/kg^{-1}), Ca (2.56 – 8.12 cmol/kg^{-1}), and Mg (0.43 – 0.89 cmol/kg^{-1}) are all above the specified favourable limit. The results obtained shows that soils in the study area have been degraded as compared to the soil quality ratings for tropical soils.

Soil Properties	Favourable	Unfavourable	Possible Causes
Bulk Density	Dutsen-Abba (1.39), Kufena (1.07) and Dambo (1.15)	Zabi (1.62)	Compaction from cattle grazing or cultivation, tramping by humans, etc
Porosity	Dutsen-Abba (47.55), Kufena (59.6) and Dambo (56.6)	Zabi (38.9)	

pH		Dutsen-Abba (7.89), Kufena (4.40) Dambo (8.63), and Dogarawa (8.43)	
Organic carbon		Dutsen-Abba (1.28), Kufena (1.40), Dambo (1.03) and Zabi (1.55)	sparse vegetation cover and persistent cultivation
CEC (mg/L)	Dutsen-Abba (15.4), Kufena (23.5), Dambo (14.4) and Zabi (20.9)		use of excess fertilizers
Na		All unfavorable	
K		All unfavorable	
Ca		All unfavorable	
Mg		All unfavorable	

Source: (Haruna, 2019)

Principal Component Analysis (PCA)
Principal component analysis is a great technique for pattern recognition that explains the variance of a large set of inter-correlated variables. The principal components (PCs) are the uncorrelated (orthogonal) variables, gotten by multiplying the original correlated variables with the eigenvector. For the purpose of this study, the component was extracted based on the scree plot to explain the total variance among the components and the varimax rotation to explain the component matrix. The Scree plot diagram shows a way of determining the useful components to consider based on the Eigen values which results in a change in the slope of the plot from steep to shallow as observed in figure 1. Hence, Eigen values greater than 1 is used to determine useful components to be used for the analysis.

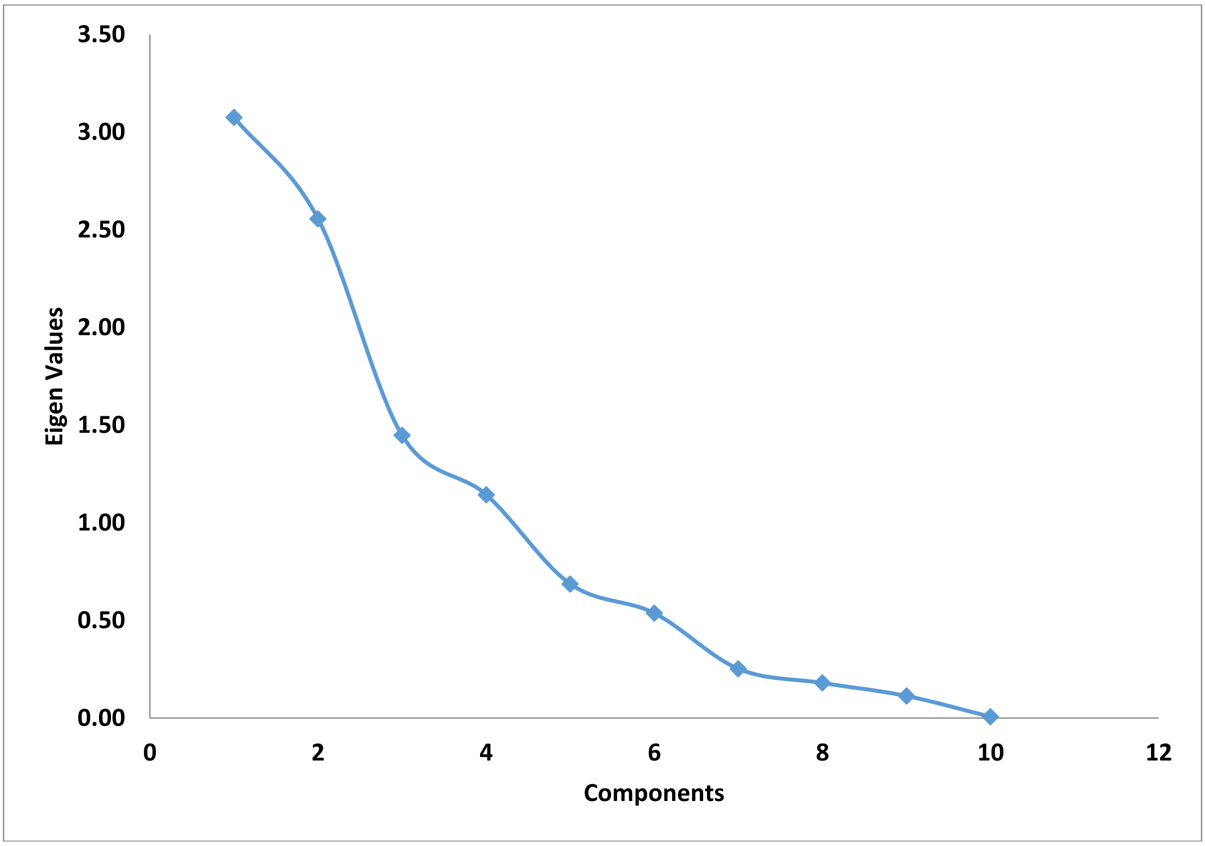

Figure 2: Scree Plot for PCA

The Scree plot from Figure 1 shows that: components 1, 2, 3, and 4 have Eigen values greater than 1 and cumulatively contributes 82.2% in predicting land degradation within the study area. Hence, components 5 to 10 will be discarded from the Principal Component Analysis (PCA) and only components 1-4 will be retained.
The result from Table 5 shows that: component 1 explains 30.8% of soil degradation, component 2 explains 25.6%, component 3 explains 14.5%, and component 4 explains 11.4% with a cumulative value of 82.2% variance explained by the four components. Also, according to Lal (2015) factor loadings can be categorised as strong, medium and weak conforming to values of >0.75, 0.75 – 0.50, and <0.50 respectively. A factor loading greater than 0.75 is chosen as the parameter that most influences land degradation in this study, and Table 5 portrayed PC1 parameters of Bulk density (0.963), Porosity (-0.954), GMC (-0.287), Organic carbon (-0.77) and CEC (0.29) have strong effects on land degradation. PC2 explains CEC (0.753), Na (-0.513) and K (-0.88) to have effect on land degradation. PC3 explains parameters of

Organic carbon (0.391), CEC (-0.221) and Na (0.205) to have strong impact on land degradation. While Organic carbon (0.822), CEC (0.395), Na (-0.178) and K (-0.149) have strong impacts on land degradation in PC4. However, the PCA shows that bulk density and porosity have the highest influence on land degradation followed by potassium, magnesium, organic carbon, calcium, pH, GWC, and CEC, whereas sodium (0.533) have a low impact on soil degradation.

Table 5: Component Matrix

Soil Sample Parameters	Component 1	2	3	4
Bulk Density (g/cm3)	.963	.031	.189	.039
Porosity	-.954	-.014	-.164	.113
GMC	-.287	.768	.185	-.293
ph	.080	-.075	.322	-.793
Organic Carbon (%)	-.077	.217	.391	.822
CEC (mg/L)	.029	.753	-.221	.395
Na	.533	-.513	.205	-.178
K	.184	-.088	.898	-.149
Ca	.308	.813	.148	.308
Mg	.217	.099	.838	.092
% Variance Explained	30.757	25.566	14.476	11.440
% Cumulative Explained	30.757	56.323	70.799	82.238

Source: (Haruna, 2019)

Correlation Analysis

Pearson Correlation analysis was performed in order to determine the relationship of a soil parameter to another. From the analysis values with a single astheric ("*") are significant at 95% confidence level (0.05 significance level), and values with double astheric ("**") are significant at 99% confidence level (0.01 significance level).

The result of the analysis from Table 5 shows that porosity is negatively correlated with bulk density (-0.978), which implies that as porosity in the soil sample reduces; the bulk density increases and vice versa. Also from the result, as CEC increases, organic carbon increases. In terms of the exchangeable bases, as potassium content in the soil sample increases, pH value and sodium content increases. More also, as calcium content increases in the soil sample organic carbon and CEC content increases. Finally, as magnesium content increases, calcium content in the soil sample also increases.

Table 6: Pearson Correlation Analysis of Soil Samples

	Bulk Density	Porosity	GWC	Ph	Organic Carbon	CEC	Na	K	Ca	Mg
Bulk Density	1									
Porosity	-.978**	1								
GWC	-.193	.145	1							
Ph	.125	-.190	.087	1						
Organic carbon	.067	.080	.064	-.359	1					
CEC (mg/L)	-.013	.101	.339	-.238	.451*	1				
Na	.414	-.413	-.202	.429	-.024	-.172	1			
K	.330	-.336	.175	.457*	.243	-.214	.570**	1		
Ca	.342	-.264	.413	-.074	.446*	.665**	.020	.199	1	
Mg	.394	-.346	.050	.210	.313	-.111	.055	.634**	.304	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Source: (Haruna, 2019)

The result from Table 6 coupled with that from Table 5 shows that pH is highly correlated with sodium and potassium content in the soil samples, and potassium have been found from table 1 as a major cause of land degradation.

Conclusion

From the findings of this study, it is clear that compaction which can originate from various activities such as grazing by cattles and continuous trampling by human are major causes of land degradation. The soil samples generally have low organic carbon content which is also an indication of land degradation. Also, the soil samples have high pH values as a result of high use of fertilizers on the farmland which proves that most farmlands are less fertile and highly degraded which in turn leads to high presence of exchangeable bases in the soil samples. However, the PCA shows that bulk density and porosity have the highest impact on land degradation followed by potassium, magnesium, organic carbon, calcium, pH, GWC, and CEC, whereas sodium have a low impact on soil degradation.

RECOMMENDATION

At the end of the research and following the outcome of findings, the researchers recommend the following;

i. Farmlands should also be fenced to avoid illegal intrusion of cattle's that are potentially causing compaction and damage to soil structure.

ii. Practice of use of organic manure should be encouraged amongst the farmers in order to improve soil structure.
iii. Farmers should be educated on causes and menace of soil erosion and methods of minimizing/eradicating it.
iv. Farmers should be encouraged to practice terracing and tree planting as ways of preventing land degradation due to wind and or water erosion.

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