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Spatial Variability of Soil Properties around Baturiya Sanctuary, Jigawa State, Nigeria

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Abstract: Soil properties intricately vary spatially owing to several natural and anthropogenic factors including parent material, terrain as well as land use. The aim of this study is to assess the spatial variability of soil samples collected from three different land use types namely: reserved area, parkland and farmland around Baturiya Sanctuary, northwestern Nigeria with a view to providing information that will assist the government in planning and conservation of the area. Free traverse sampling technique was used to collect soil samples at the depth of 0-30cm. Laboratory analysis was done for the following parameters: bulk density, PSD, phosphorous, pH, EC, total nitrogen, exchangeable bases (Mg, Na, and K), and CEC. Geostatistical technique (semivariogram analysis) was used to test variation in soil properties. Result of the study depicted that It also indicated that BD (1.24 g/cm3), clay (22%), total nitrogen (0.25 g/kg), available phosphorous (32.61 mg/g), OC (1.6%) and Mg (0.05) are highest in reserved area. Also sand (55%) and silt (29%), pH (5.0), EC (522), Na (0.007), K (0.44) and CEC (4.5meq/100g) are highest in farmland. The variogram based nugget-sill ratio showed strong dependency with 0 (N, EC, OC) and weak dependency 1 (BD, Na) on the scale of 0.25 high, 0.25 – 0.75 moderate and 0.75 weak. In conclusion, this study found that soil properties in area showed high to moderate spatial dependency except for BD, Mg, K, and Na which showed low spatial autocorrelation owing increasing human activities in the area. This study depicted that apparently limitation by few samples have influenced the pattern in the result otherwise spatial variability of certain elements may be more discernible and beyond reasons such land use and parent materials.

Keywords: Soil, geostatistics, semivariogram, land use, wetland

1. Introduction

Soil is the most basic of all resources; it is the essence of all terrestrial life and cultural heritage (Bini & Zilioli, 2013). Soil is a non-renewable resource. Therefore, it is vital to know the complex interactions between processes, factors and causes occurring at a range of spatial and temporal scale (Lal, 2015). Soils are characterised by a high degree of spatial variability because of the combined effects of physical, chemical, and biological processes that operate with different intensities and at different scales (Awal et al., 2019) and depending on differences in genetic and

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environmental factors (Santra, Chopra, & Chakraborty, 2008). Based on the need to ensure precision in decision making, it is important to assess the relationship between soil and various land-use type, including forests, agriculture, grazing, fallow as well as parklands (Wall & Six, 2015). It is well established that different land uses and management practices greatly impact the soil properties (Spurgeon, Keith, Schmidt, Lammertsma, & Faber, 2013; Adamu & Yusuf, 2014). The knowledge of variation in soil properties within various systems is essential in determining production constraints and the related soil issues such as accelerated erosion, depletion of the soil organic carbon (SOC) pool, biodiversity loss, elemental imbalance (toxicity or otherwise), and toxicity (acids and salt) (Dlamini et al., 2014; Lal, 2015). According to Tola et al. (2017), an understanding of the spatial variability of soil Physico-chemical characteristics in both forms is necessary for planning and management of land use.

Many studies have been conducted to show a significant relationship between soil quality and land use type (Iqbal et al., 2014; Lal, 2015; Deng et al., 2016). However, while a plethora of traditional statistical techniques are available for quantifying the spatial distribution of soil properties, arguably, the concern over increasing soil variability in semi-arid areas such as northern Nigeria necessitates the use of geostatistics. In the last few decades, the effects of cultivation on soils' physical and chemical properties are known under experimental conditions only. However, few attempts have been made to monitor such effects under smallholder conditions (Mortimore, 1989). There have been notable studies on spatial variability of soil properties in Nigeria which reported changes in soil properties using conventional methods (Essiet,1990; Yusuf,1994; Ogeh & Ogwurike, 2006; Lawal et al. 2009; Senjobi & Ogunkunle 2011; Maconachie 2012; Adamu & Yusuf,2014; Shehu et al.,2016; Ali et al., 2019). Arguably, except for Maina et al. (2012), Ahmed (2015), Lawan et al. (2020), most of the studies mentioned above and more examples (MARDITECH, 2011; Adamu, 2013; Ahmed et al., 2015) focused on soil fertility and management, suitability mapping and quality characterisation using conventional methods. Certainly, there is a lack of knowledge concerning the use of geostatistical approaches to assess soil variability in large geographical locations with mosaic land uses. Therefore, this study applied the semivariogram model, which shows spatial dispersion between samples closer to one another and those separated by larger distances in Baturiya Sanctuary, northwestern Nigeria. This method is the best to characterise the structure of spatial continuity (Mulla & McBratney, 2002; Acerbi Junior et al., 2015). Semivariogram measures the degree of dissimilarity between observations as a distance function (Karl & Maurer, 2010). It measures a spatial random field; how much samples collected from the area can vary in properties depending on the distance between those samples.

Given the importance of soil variability to users at the landscape scale (Hu et al., 2019) and to monitor the large geographical area for precision and planning, the use of semivariogram analysis is timely in this study. It is also important because the effects of anthropogenic activities on soil properties are discernible around Baturiya Sanctuary. As it has been reported by Hadejia et al. (2020), the area is facing intensification and over-exploitation of natural resources, which significantly affects its ecological balance and socio-economic well-being of the people. These conflicting uses of parkland and farmland are alarmingly expanding in the area, thereby severely degrading resources, particularly soils.

2. Study Area

Baturiya Sanctuary is part of the Baturiya Game Reserve located in Jigawa State, Northwestern Nigeria (Figure-1). It lies on latitude 12º31'N and 12º39'N and longitude 10º29'E and 10º31'E. The reserve covers an area of 320 sq km with a buffer zone of a half kilometre. The area is a wetland and presently protected under the RAMSAR convention 1971 protocol. Site number 1752 of the RAMSAR convention (Adams, 1993) is a Sudano-Sahelian floodplain wetland comprising ponds and water holes recharged yearly by inundation. The area provides a natural habitat for over 378 species of migratory birds from places as far as Europe and Australia for nesting and breeding (BirdLife International, 2015; Ringim et al., 2015). It is endowed with mosaic resources, including permanent lakes, seasonally flooded pools, and inundated channels that provided valuable products to humans and animals.

The climate of the wetland is characterised by two distinct seasons; wet (May-September) and dry season (October-April), rainfall is between 500- 600 mm, whereas temperature ranges from 12°C during harmattan season (cold) to about 40°C during the hot season, rainfall is between 500- 600 mm, with a mean minimum temperature of 12°C during December to January, to a maximum of 40°C during April (Ogunkoya & Dami, 2007) Dry, dusty, cool North Easterlies (Harmattan winds) are prevalent between November and March. The mean minimum temperature, 12°C is in January, while the hottest period is in April during the inter-season period with a mean maximum temperature of 40°C.

A large rural population within and around the wetlands pursue livelihoods activities such as the cultivation of the floodplains, fishing, pastoralism and harvesting of wild resources (Hadejia et al., 2020). The multiple-use management approach of the Jigawa State Government inhibits sustainable and rational use of the wetland resources. The area is also surrounded by many smallholder farming and artisanal communities. It provides resources to tens of thousands of rural dwellers, especially those residing in Gafta (6 km west), Shiyo (5 km southwest), Shinge (4 km west), Illala (12 km west), Fandum (11 km west), Kaiwari (4 km north), Kokiro (3 km east), Marawaji (4 km east), Zigobiya (7 km east), Una (3 km east), Barmaguwa (5 km east), and Abanaguwa (5 km north). The surge in illegal fuelwood harvesting around the reserve has negatively affected the area. As a result of anthropogenic activities, the area suffers from several ecological challenges such as siltation, loss of biodiversity and blockage of inundated channels. This study considers three adjacent land use types, namely, reserved (protected), parkland (the area where trees and farming activities occur simultaneously) and farmland (unprotected by law).

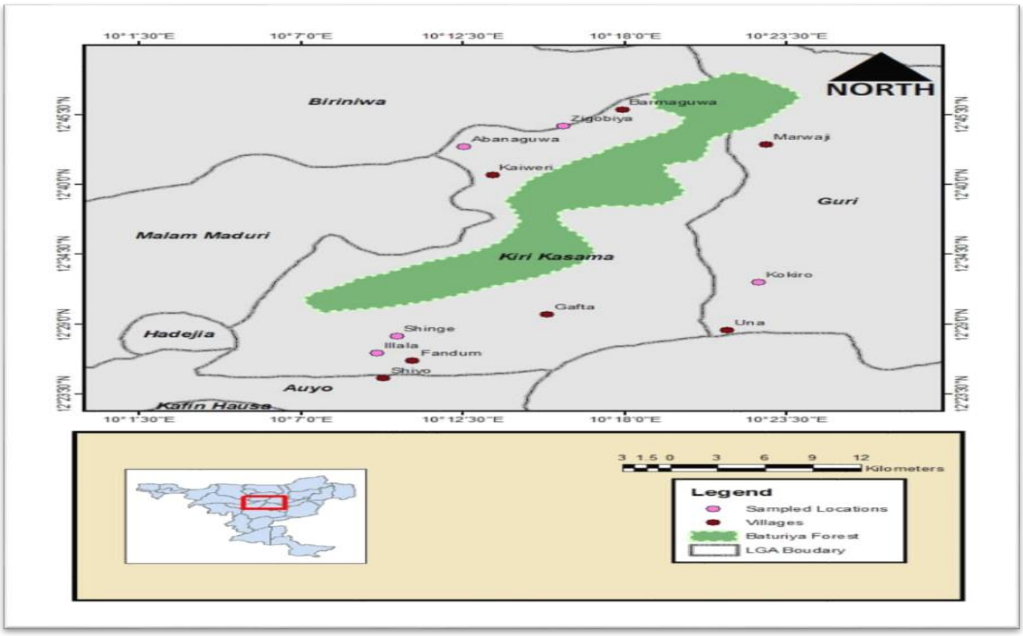


Fig. 1 - Map of Baturiya Sanctuary, Northwestern Nigeria

3. Materials and Methods

The study assesses three adjacent land use types, namely, reserved, parkland and farmland. Samples were collected at 0-30 cm depth in March 2019 using a stratified random sampling technique in line with Peterson and Calvin (1986). The study area was first categorised according to morphology and divided into fairly homogenous units as such relief and vegetation, based on the assumption that land use indicates soil differences (Figure 2).

Ten random undisturbed soil core samples were collected from each land use type with an auger to avoid contamination. The samples were gently placed in a polythene bag, and each of them was given unique laboratory numbers for identification. A sheet was used to take some field information of the soil, including its nature, management history, crop species grown, and water logging conditions. After that, the collected samples were taken to the laboratory for analysis. At the laboratory, the samples were air-dried, grounded with a wooden pestle and mortar so that the soil aggregate is crushed gently to avoid breaking down the particles. The soil is then passed through a 5 mm sieve and analysed for nine soil properties: bulk density, particle size distribution, texture, available phosphorus, pH, total nitrogen, electrical conductivity, organic matter, and exchangeable acids.

The soil pH was determined in a glass electrode pH meter (Mclean, 1965), while the total nitrogen was determined by the macro-Kjeldahl digestion methods (Jackson, 1958). Phosphorous (p) content was determined using the colourimeter (CECIL CE 373) method using the sodium hydrogen carbonate extraction in line with Bray and Kurtz (1945) method. Exchangeable cations: potassium (K), sodium (Na) and Magnesium (Mg) were determined using a flame photometer and atomic absorption spectrophotometer respectively, PSD was done using Bouyoucos (1951) method while USDA Textural triangle was also used for determining textural classes. The data were used to map the distribution of soil properties and analysis of variability using semivariogram tool in ARC GIS 10.5 statistical software to depict spatial autocorrelation of the measured sampling locations. Semivariogram model is mathematically written as (FAO, 2003):

$$y*(h)=\frac{1}{2n}\sum_{i=1}^{n}(z(x_i)-z(x_i+h))^2$$ ………. Equation 1

Where $n(h)$ is the number of samples separated by distance h and z_{i+h} is the soil property's value a distance, h away from the location where sample z_i was sampled.

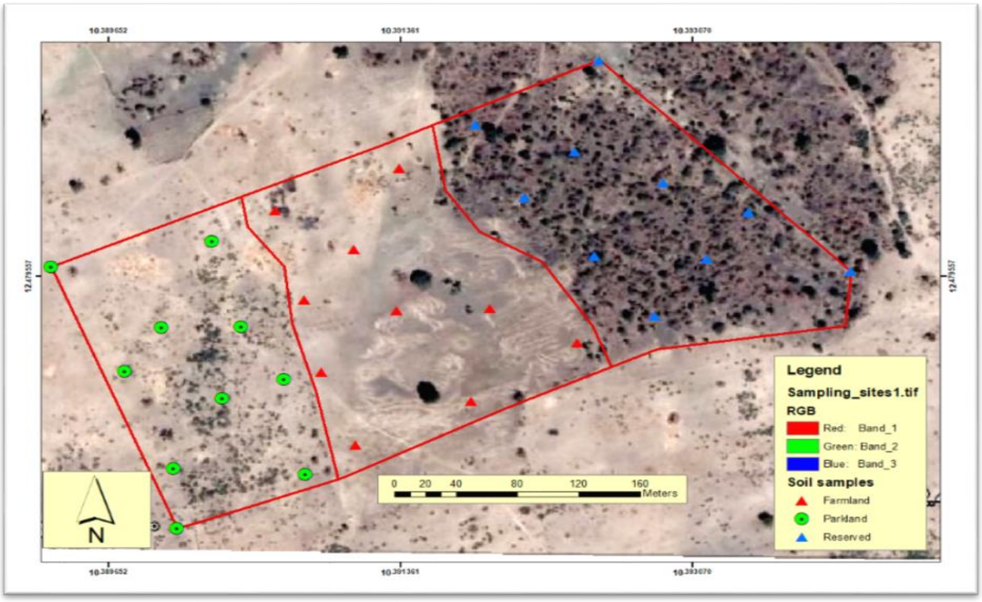
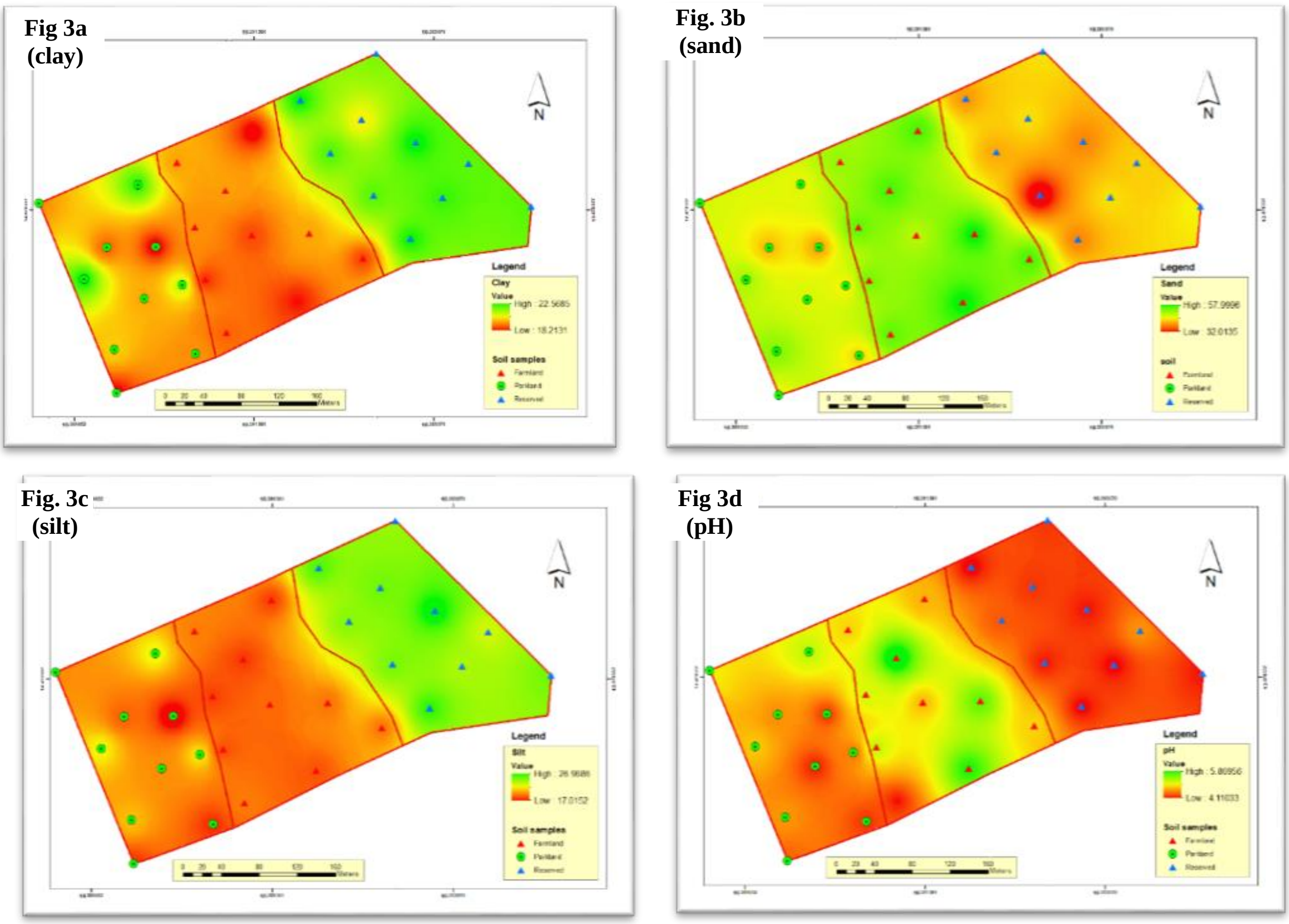


Fig. 2 - Sampling Points

4. Results

This section presents the results of the study obtained from 30 samples for soil physical and chemical properties. Soil physical and chemical properties are presented in Table 1 and Table 2, respectively. The spatial distribution of soil properties across the three land-use types is presented in Figure 3. Soil variability (semivariogram analysis) is presented in Table 3.



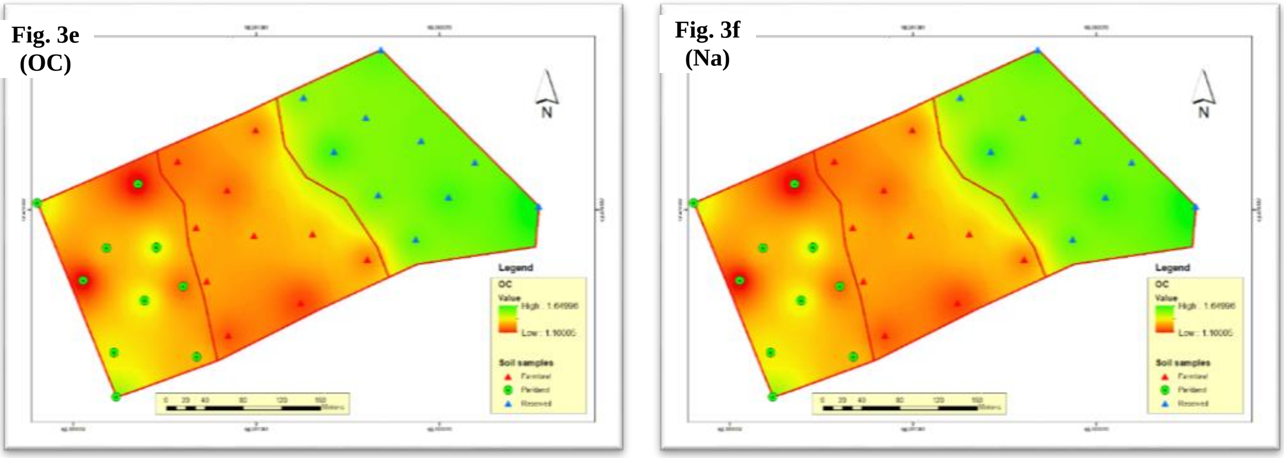
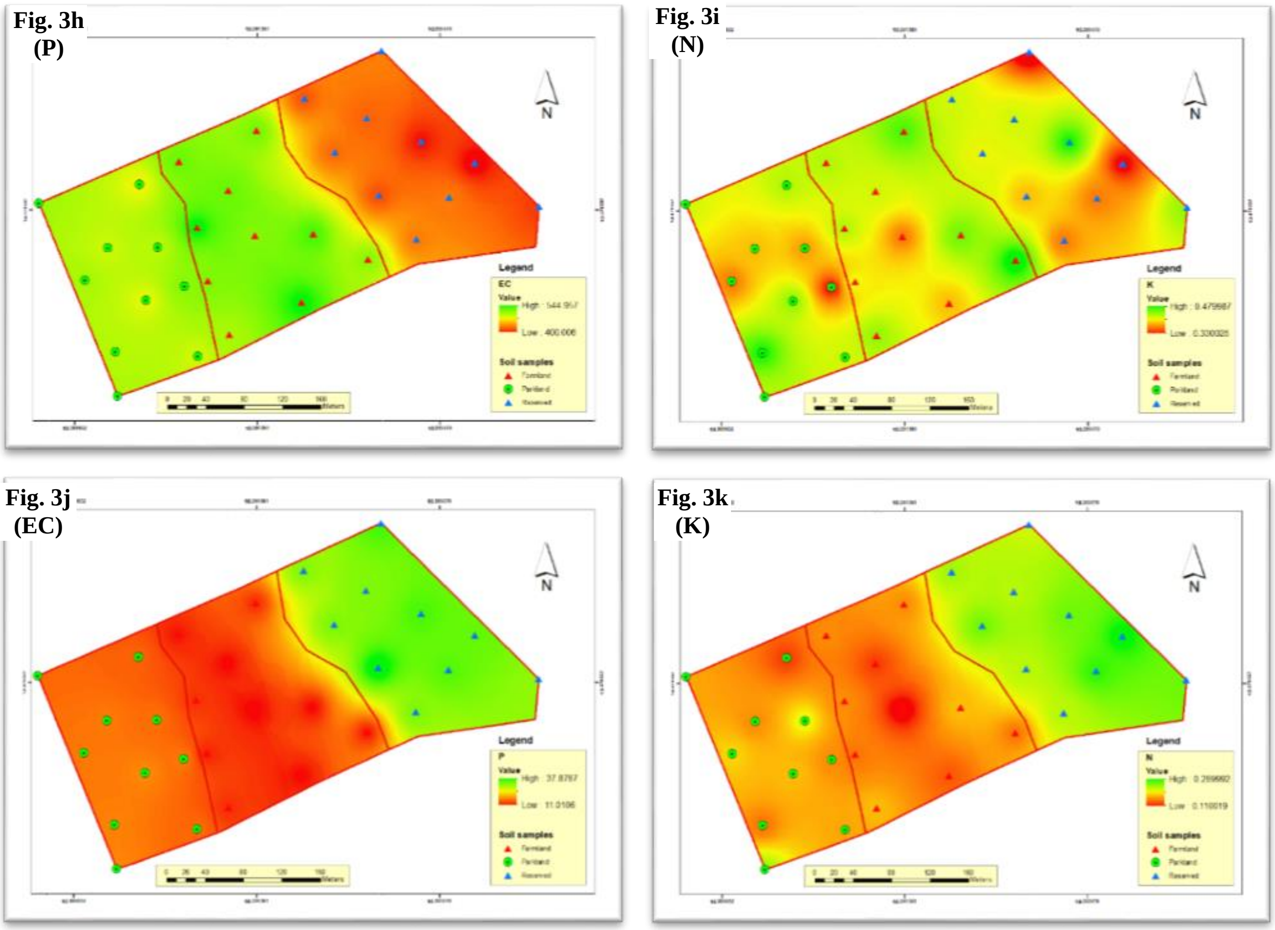
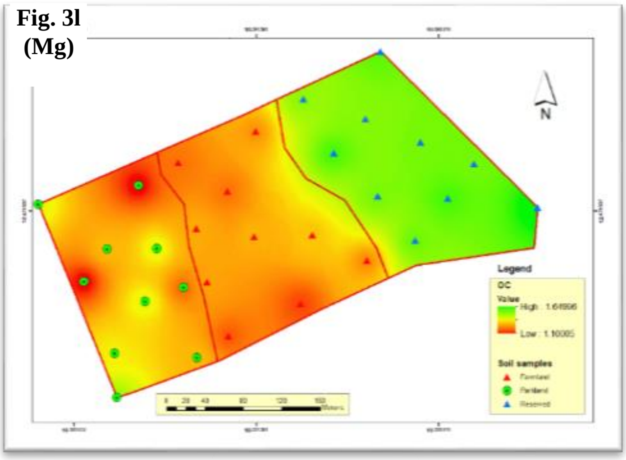


Fig. 3 - (a-f): Spatial Distribution of Soil Properties in three Land Use Types
Key: OC = organic carbon, Na = sodium,





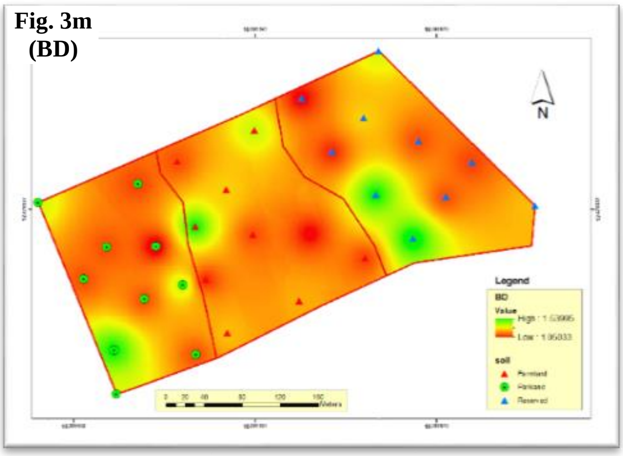


Fig. 3 (h-m): Spatial Distribution of Soil Properties in three Land use Types

Key: OC = organic carbon, Na = sodium, P = phosphorous, N = Nitrogen, K = potassium, Mg = magnesium, EC = electric conductivity, BD = bulk density

Soil Physical and Chemical Properties

Table 1-Physical Properties of Soil on Three Land Use Types

SN	Parameters	Land Use Types		
		Parkland	**Reserved Area**	**Farmland**
1	Bulk Density (g/cm^3)	1.21	1.24	1.21
2	Particle Size Distribution			
i	Percentage Sand	47	42	55
ii	Percentage Silt	27	25	29
iii	Percentage Clay	20	22	19
3	Texture	Sandy Loam	Sandy Loam	Sandy Clay Loam

Table 2-Chemical Properties of Soil on Three Land Use Types

SN	Parameters	Land Use Types		
		Parkland	**Reserved Area**	**Farmland**
1	Available phosphorus (mg/g)	15.74	32.61	11.45
2	pH	4.5	4.2	5.0
3	Total nitrogen (g/kg)	0.18	0.25	0.15
4	Electrical conductivity	493	419	522
5	Organic carbon (%)	1.3	1.6	1.2
6	Na	0.005	0.004	0.007
7	K	0.41	0.40	0.44
8	Mg	0.03	0.05	0.02
9	CEC (meq/100g)	4.3	2.5	4.5

Table 3-Semivariogram

SN	Variable	Model	Range	Partial Sill (C)	Nugget (C_o)	Sill (C_o +C)	Ratio C_o / C_o +C	Lag size	RMSS	RMS
1	Sand	Exponential	0.0024	47.02	8.4379	55.46	0.152	0.00021	0.955	5.551
2	Silt	Tetraspherical	0.0004	14.911	1.1737	16.085	0.073	0.00046	1.078	2.078
3	Clay	Tetraspherical	0.0046	2.557	0.978	3.535	0.2767	0.00039	0.011	1.418
4	BD	Gaussian	1.0056	0	0.022	0.022	1	0.0005	0.74	0.1637
5	P	J-Bessel	1.0044	104.6	5.513	110.113	0.05	0.00036	1.601	4.458
6	pH	Gaussian	0.0019	0.2278	0.0937	0.3215	0.2914	0.00019	1.045	0.409
7	N	Spherical	0.0014	0.0041	0	0.0041	0	0.0004	1.1529	0.032
8	EC	Exponential	0.005	3296.64	0	3296.64	0	0.00044	0.7625	22.48
9	OC	Pentaspherical	0.0055	0.049	0	0.049	0	0.00046	1.23	0.1153
10	Na	Exponential	0.0009	0.00002	4.207	4.207	1	0.00011	0.992	0.001
11	K	Rational Quadratic	0.00056	0.00025	0.0014	0.00165	0.8484	0.0005	1.068	0.043
12	Mg	Circular	0.0056	0.00035	9.382	9.382	0.9	0.00045	1.092	0.014
13	CEC	Hole Effect	0.0047	1.3262	0.048	1.3742	0.0349	0.0045	1.825	0.48

4.1 Spatial Distribution of Soil Properties

The spatial distribution of soil parameters indicated a concentration of clay particles in the reserved area with low sandy materials. Findings showed that K is moderate in the reserved area while Mg and Na have a high farmland concentration (Figure 3 f, k & l). This suggests that there is high use of artificial fertiliser on farmland which causes recurring microbial activities. This study corroborates Maina et al. (2012) and Ahmed (2015), which indicated that farming activities could destabilise PSD soils of the dryland areas. The distribution of high OC, N and P around the reserved area indicates protected help in soil reclamation (Figure 3 e, h & i). This result supports Jahknwa and Ray (2014), who reported that the absence of anthropogenic activities at that particular soil depth helps preserve exchangeable bases. It also affirms Bostani et al. (2017), who indicated that pH, CEC, calcium carbonate, and OM showed spatial variation in Iran's Ghazvin Plains.

4.2 Soil Physical and Chemical Properties

Soil physical affects chemical and biological processes and plays a crucial role in soil quality indicators (Dexter, 2004). Results of the study depict that BD (1.24 g/cm^3), clay (22%) are high in the reserved area (Table 1). Also total nitrogen (0.25 g/kg), available phosphorous (32.61 mg/g), OC (1.6%) and Mg (0.05) were highest in reserved area. The results also indicate that sand (55%) and silt (29%) (Table 1) as well as pH (5.0), EC (522), Na (0.007), K (0.44) and CEC (4.5meq/100g) (Table 2) were highest in the highest in farmland. In line with Liu et al. (2006), Franzluebbers and Stuedmann (2010), Saha et al. (2012) as well as Guan et al. (2017), which show significant effects of land use on soil properties in various parts of the world, this study suggests that anthropogenic factors are linked to the high concentration of sand and silt on farmland and parkland in the area.

4.3 Statistical Analysis

Soil properties vary tremendously in their ranges of spatial autocorrelation (Mulla & McBratney, 2002). In this study, the variogram was fitted to the theoretical model, namely, spherical, exponential, nugget effect and Gaussian. The principle in the model has been applied as nugget variance (C_o), sill (C_o+C), and spatial dependency Co/(Co+C). The result of the analysis showed that spatial dependency is considered strong when the values of $C_o/(C_o+C)$ is less than 0.25, a moderate 0.25 – 0.75 and weak dependency 0.75 (Table 3). In line with Cambardella et al. (1994), the spatial autocorrelation here shows moderate and low dependencies with the clay of 0.27 (27%), sand of 0.15 (15%) and silt of 0.07 (7%), respectively. These indicate that despite the increasing tendency of human encroachment, the distribution is still a natural occurrence. Similarly, the concentration of pH 0.29 (29%) indicates a moderate dependency and an interplay of both anthropogenic and natural factors. The spatial dependency indicates a weak spatial correlation with BD - 1.00 (100%), Mg - 0.90 (90%), K - 0.85 (85%), and Na - 1.00 (100%). Similarly, the distribution of P, N, EC, OC and CEC shows a strong spatial correlation with 0.05 (5%), 0(0%), 0(0%), 0(0%) and 0.03(3%) within the range of (0-0.25) and indicate that their distribution is as the result of natural occurrence. Although myriad factors influence soil properties variations, this study indicates that land use and parent materials could likely be a factor of strong autocorrelation of P, N, and OC.

This finding is in line with Liu et al. (2013), who reported that at short and long-range scales, variation of the same properties occurs due to land use types, terrain as well as parent material, respectively, in the agricultural region of Eastern China. The finding also confirms Bhunia et al. (2018). They reported that nugget-sill of K, N and EC were above 0.25-0.75, indicating moderate spatial autocorrelation among properties lateritic soil in West Bengal, India. The Nugget-sill ratio supports Uyan (2016) and Lawan et al. (2020), which reported that the $C_o/(C_o+C)$ showed high dependency with 0.25 among N, EC, OC and CEC. It disagrees with Guan et al. (2017), who reported that a moderate spatial dependence of N, P and K contents which were controlled by both intrinsic and extrinsic factors in Moso bamboo forests in Yong'an City, China, as well as Awal et al. (2019) who reported that BD showed the highest spatial dependency among all properties measured in agricultural fields.

5. Conclusion

Soil physical properties in the studied area showed high to moderate spatial dependency except for BD, Mg, K, and Na, which showed low spatial autocorrelation owing to increasing human activities in the area. In conclusion, this study depicted that soil properties varies and changes according to land use types. Although few samples limit this work, it depicts that increasing soil depth may give different result as the behaviour of certain elements may change with depth and anthropogenic effect. Based on the findings of this study, it is recommended that first, free human activities, particularly illegal logging and farming around the Sanctuary under the guise of 'multiple-use management approach' of Jigawa State Government should be regulated to avoid escalation of ecological stress such as increasing siltation of ponds and flood plains; and second, detailed assessment of land uses, and soil is required using larger samples in order to identify the sources of spatial variability at each spatial scale for restoration of the ecosystem.

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