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 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 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 a 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 characterized 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
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 have great impacts on 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 with a view to show significant relationship between soil quality and land use type (Iqbal et al., 2014; Lal, 2015; Deng et al., 2016). However, while plethora of traditional statistical techniques is 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 the physical and chemical properties of soils are known under experimental conditions only but 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; Shetu et al., 2016; Ali et al., 2019). Arguably, with the exception of Maina et al. (2012), Ahmed (2015), Lawan et al. (2020), most of the aforementioned studies and more examples (MARDITECH, 2011; Adamu, 2013; Ahmed et al., 2015) focused on soil fertility and management, suitability mapping and quality characterization using conventional methods. Certainly, there is lack in knowledge concerning the use of geostatistical approach to assess soil variability in large geographical locations with mosaic land uses. Therefore, this study applied 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 characterize the structure of spatial continuity (Mulla & McBratney, 2002; Acerbi Junior et al., 2015). Semivariogram measures the degree of dissimilarity between observations as a function of distance (Karl & Maurer, 2010). In soil studies, it measures spatial dependence of 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 in order to monitor 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 12°31’N and 12°39’N and longitude 10°29’E and 10°31’E. The reserve covers an area of 320 sq km with a buffer zone of a half kilometer. The area is a wetland and presently protected under the RAMSAR convention 1971 protocol. The site number 1752 of the RAMSAR convention (Adams, 1993) is a Sudano-Sahelian floodplain wetland comprising of ponds and water holes that are being 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 network of inundated channels which provided valuable products to humans and animals. The climate of the wetland is characterized 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 hot season, rainfall is between 500-600 mm, with mean minimum temperature of 12°C during the month of December to January, to a maximum of 40°C during the month of 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.
Currently, large rural population within and around the wetlands pursue livelihoods activities such as cultivation of the floodplains, fishing, pastoralism and harvesting of wild resources (Hadejia et al., 2020). 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), Shiyio (5 km southwest), Shinge (4 km west), Illala (12 km west), Fandum (11 km west), Kairwari (4 km north), Kokiro (3 km east), Marawaji (4 km east), Zigobiya (7 km east), Una (3 km east), Barmagwawa (5 km east), and Abanaguwa (5 km north). The surge in illegal fuel wood harvesting around the reserve has negatively affected the area. As a result of anthropogenic activities, the area is suffering from a number of 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 (area were trees and farming activities occur simultaneously) and farmland (unprotected by law).

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 stratified random sampling technique in line with Peterson and Calvin (1986). The study area was first categorized according to morphology and divided into fairly homogenous units as such relief and vegetation, based on the assumption that land use is indicative of 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 conditions such as water logging. Thereafter, 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 are crushed gently to avoid breaking down of the particles. The soil is then passed through 5 mm sieve and analysed for nine soil properties namely; bulk density, particle size distribution, texture, available phosphorus, pH, total nitrogen, electrical conductivity, organic matter and exchangeable acids.
The soil pH was determined in 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 colorimeter (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 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 for mapping the distribution of soil properties and analysis of variability using semivariogram tool in ARC GIS 10.5 statistical software with a view to depicting spatial autocorrelation of the measured sampling locations. Semivariogram model is mathematically written as (FAO, 2003):

$$\gamma (h) = \frac{1}{2n} \sum_{i=1}^{n} (z(x_i) - z(x_i + h))^2$$

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

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. 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 - Spatial Distribution of Soil Parameters

Fig. 3a - Spatial Distribution of Soil Parameters 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

<table>
<thead>
<tr>
<th>SN</th>
<th>Parameters</th>
<th>Parkland</th>
<th>Reserved Area</th>
<th>Farmland</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bulk Density (g/cm³)</td>
<td>1.21</td>
<td>1.24</td>
<td>1.21</td>
</tr>
<tr>
<td>2</td>
<td>Percentage Sand</td>
<td>47</td>
<td>42</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Percentage Silt</td>
<td>27</td>
<td>25</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Percentage Clay</td>
<td>20</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>Texture</td>
<td>Sandy Loam</td>
<td>Sandy Loam</td>
<td>Sandy Clay Loam</td>
</tr>
</tbody>
</table>

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

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

Table 3 - Semivariogram

<table>
<thead>
<tr>
<th>SN</th>
<th>Variable</th>
<th>Model</th>
<th>Range</th>
<th>Partial Sill (C)</th>
<th>Nugget (C₀)</th>
<th>Sill (C₀ +C)</th>
<th>Ratio C₀ / C₀ +C</th>
<th>Lag size</th>
<th>RMSS</th>
<th>RMS</th>
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<tbody>
<tr>
<td>1</td>
<td>Sand</td>
<td>Exponential</td>
<td>0.0024</td>
<td>47.02</td>
<td>8.4379</td>
<td>55.46</td>
<td>0.152</td>
<td>0.00021</td>
<td>0.955</td>
<td>5.551</td>
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<tr>
<td>2</td>
<td>Silt</td>
<td>Tetraspherical</td>
<td>0.0004</td>
<td>14.911</td>
<td>1.1737</td>
<td>16.085</td>
<td>0.073</td>
<td>0.00046</td>
<td>1.078</td>
<td>2.078</td>
</tr>
<tr>
<td>3</td>
<td>Clay</td>
<td>Tetraspherical</td>
<td>0.0046</td>
<td>2.557</td>
<td>0.978</td>
<td>3.535</td>
<td>0.2767</td>
<td>0.00039</td>
<td>0.011</td>
<td>1.418</td>
</tr>
<tr>
<td>4</td>
<td>BD</td>
<td>Gaussian</td>
<td>1.0056</td>
<td>0</td>
<td>0.022</td>
<td>0.022</td>
<td>1</td>
<td>0.0005</td>
<td>0.74</td>
<td>0.1637</td>
</tr>
<tr>
<td>5</td>
<td>P</td>
<td>J-Bessel</td>
<td>1.0044</td>
<td>104.6</td>
<td>5.513</td>
<td>110.113</td>
<td>0.05</td>
<td>0.00036</td>
<td>1.601</td>
<td>4.458</td>
</tr>
<tr>
<td>6</td>
<td>pH</td>
<td>Gaussian</td>
<td>0.0019</td>
<td>0.2278</td>
<td>0.0937</td>
<td>0.3215</td>
<td>0.2914</td>
<td>0.00019</td>
<td>1.045</td>
<td>0.409</td>
</tr>
<tr>
<td>7</td>
<td>N</td>
<td>Spherical</td>
<td>0.0014</td>
<td>0.0041</td>
<td>0</td>
<td>0.0041</td>
<td>0</td>
<td>0.0004</td>
<td>1.1529</td>
<td>0.032</td>
</tr>
<tr>
<td>8</td>
<td>EC</td>
<td>Exponential</td>
<td>0.005</td>
<td>3296.64</td>
<td>0</td>
<td>3296.64</td>
<td>0</td>
<td>0.00044</td>
<td>0.7625</td>
<td>22.48</td>
</tr>
<tr>
<td>9</td>
<td>OC</td>
<td>Pentaspherical</td>
<td>0.0055</td>
<td>0.049</td>
<td>0</td>
<td>0.049</td>
<td>0</td>
<td>0.00046</td>
<td>1.23</td>
<td>0.1153</td>
</tr>
<tr>
<td>10</td>
<td>Na</td>
<td>Exponential</td>
<td>0.0009</td>
<td>0.00002</td>
<td>4.207</td>
<td>4.207</td>
<td>1</td>
<td>0.00011</td>
<td>0.992</td>
<td>0.001</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>Quadratic</td>
<td>0.00056</td>
<td>0.00025</td>
<td>0.0014</td>
<td>0.00165</td>
<td>0.8484</td>
<td>0.0005</td>
<td>1.068</td>
<td>0.043</td>
</tr>
<tr>
<td>12</td>
<td>Mg</td>
<td>Circular</td>
<td>0.0056</td>
<td>0.00035</td>
<td>9.382</td>
<td>9.382</td>
<td>0.9</td>
<td>0.00045</td>
<td>1.092</td>
<td>0.014</td>
</tr>
<tr>
<td>13</td>
<td>CEC</td>
<td>Hole Effect</td>
<td>0.0047</td>
<td>1.3262</td>
<td>0.048</td>
<td>1.3742</td>
<td>0.0349</td>
<td>0.0045</td>
<td>1.825</td>
<td>0.48</td>
</tr>
</tbody>
</table>

4.1 Spatial Distribution of Soil Properties

The spatial distribution of soil parameters indicated a concentration of clay particles at the reserved area with low sandy materials. Findings showed that K is moderate in the reserved area while Mg and Na have high concentration at farmland (Figure 3 f, k & l). This suggests that there is high use of artificial fertilizer at farmland which causes recurring microbial activities. This study corroborates findings of Maina et al. (2012) and Ahmed (2015) which indicated that farming activities can destabilize 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 Jahkwa and Ray (2014) who reported that the absence of anthropogenic activities at that particular soil depth help in
preservation of exchangeable bases. It also affirms Bostani et al. (2017) who indicated that pH, CEC, calcium carbonate, and OM showed spatial variation in Ghazvin Plains of Iran.

4.2 Soil Physical and Chemical Properties

Soil physical affects chemical and biological processes and therefore, plays a crucial role in the indicators soils quality (Dexter, 2004). Results of the study depict that BD (1.24 g/cm³), 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 Stuedemann (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 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 theoretical model namely; spherical, exponential, nugget effect and Gaussian. The principle in the model has been applied as nugget variance ($C_0$), sill ($C_0+C$) and spatial dependency $C_0/(C_0+C)$. Result of the analysis showed that spatial dependency is considered strong when the values of $C_0/(C_0+C)$ 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), spatial auto correlation here shows a moderate and low dependencies with clay of 0.27 (27%), sand of 0.15 (15%) and silt of 0.07 (7%) respectively. These indicate that despite 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 variations of soil properties, this study indicates that land use and parent materials could likely be a factor 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 same properties occurs due to land use types, terrain as well as parent material respectively in agricultural region of Eastern China. The finding also confirms Bhunia et al. (2018) who reported that nugget-sill of K, N and EC were above 0.25-0.75 indicating moderate spatial autocorrelation among properties of lateritic soil in West Bengal, India. The Nugget-sill ratio supports Uyan (2016) and Lawan et al. (2020) which reported that the $C_0/(C_0+C)$ 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 increasing human activities in the area. In conclusion, this study depicted that soil properties vary and changes according to land use types. Although this work is limited by few samples, but it depicts that increasing soil depth may give different result as the behavior of certain elements may change with depth and anthropogenic effect. Based on the findings of this study, it is recommended that first, unrestricted 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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References


