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EFFECT OF FLOOD ON THE SOIL QUALITY OF THE RIMA RIVER FLOODPLAIN IN WAMAKKO LGA, SOKOTO STATE, NIGERIA

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Abstract

Quantitative assessment of soil quality change after flood is potentially beneficial for soil fertility management. Thus, this study assessed the effect of the 2016 flooding of the Rima River floodplain on the soil quality. With the aid of a 3-m accuracy Global Positioning System (GPS) hand-held receiver, soil samples were randomly augered from thirty-one (31) plots at 0-30cm depth in March/April, 2016 (pre-flood season) and in October/November, 2016 (post-flood season). Standard laboratory procedures were applied to determine the concentrations of pH, Potassium (K), Nitrogen (N), Phosphorus (P), Calcium (Ca), Magnesium (Mg), Soil Organic Carbon (SOC) and Particle size. Inverse Distance Weighting (IDW) was used to interpolate the soil particle sizes for textural mapping. Chi-Square goodness of fit was used to test for difference among observations for each season, while Analysis of Variance (ANOVA) by General Linear Model (GLM) was used to test the difference in properties between both seasons. Results showed significant changes ($P<0.05$) in the measured soil properties between pre-flood and post-flood seasons. The study concluded that the 2016 flood largely affected the soil quality of the study area. It was recommended that soil quality change be assessed annually in the floodplain for sustainable soil management.

Keywords: Flood; Rima Floodplain; Soil Quality; Inverse Distance Weighting

Introduction

Agriculture was a front burner of the Federal Government's schemes in the late 1970s, and part of the efforts towards agricultural self-reliance was the establishment of the River Basin Development Authority (RBDA) in 1979 (Ojo et al., 2009). It was meant to ensure dry season agriculture so as to boost employment and food security, increase variety of crops, curtail annual dry season exodus of farmers and rural dwellers, and foster agro-allied industrial development, among others. This saw the construction of various dams and projects across the country, one of which is Goronyo dam located on the upper course of the Rima River in Sokoto State (Adeniyi, 1993; Muhammad, 2002; Ojo et al, 2009).

The Rima River Basin is located in the Sudano-sahelian area of Nigeria which is characterised by prolonged dry season; thus, farmers in this area have relied on irrigation for centuries (Ojo et al., 2009). The Goronyo dam was constructed in 1984 to regulate the hydrological flows of the river in favour of all-the-year-round farming in the vast floodplain of the Rima River. Thus, the floodplain hosts thousands of farmers who cultivate rice, onion, garlic, wheat, sorghum and other moisture sensitive highly valued vegetable crops largely at subsistence and sparingly at commercial levels (Ojo et al., 2009). Due to increases in annual rainfall amounts, consequent upon climate change and the poor management of the dam, submergence of the floodplain by the river is annually a recurrent phenomenon (Abdulrahim and Eniolorunda, 2012).

Floods are the most common and widespread of all natural disasters (Clement, 2012), although they have both negative and positive impacts on the soil. It may in the short-term be destructive but can be considered as an important factor in the process of soil formation and a source of enhancing soil productivity due to alluvial deposition in the long-term (Ahmad, 2011). It affects soil aeration as a result of acute shortage of oxygen; as such, soil microorganisms are not very effective at decomposing crop residues and organic matter when the soil is saturated, slowing the denitrification process and uptake of Phosphorus (Johnston, 2001; Pezeshki, 2001; Yanga et al., 2004; Sawyer, 2011; Bly, 2015). Prolonged oxygen shortage results in root die-back and susceptibility to attack by root-rot organisms. In their study, Liu et al. (2014) affirmed that flood could reduce the plant biomass of roots and overall photosynthetic capability of plants. Further, flood increases the pH of acid soils and decreases the pH of alkaline soils. Haapala et al. (1975) established a strong positive correlation between pH and water level of the River Kiiminkijoki, Finland. It was attributed partly to the acidifying effect of rain and melt water and abundance of peat in the area. Relatedly, Sun et al. (2007) observed that soil pH increased with flood time in a contaminated soil in China. Nitrate nitrogen and Sulfate can be lost by leaching down and out of the reach of crops; this is besides the slow rate of Nitrogen release due to ineffective rate at which decomposition of crop residues and organic matter when the soil is saturated (Johnston, 2001).

Soil fertility is linked to the physical, chemical, biological, climatic and anthropic characteristics of the site, and once the soil is capable of supplying 13 of the 16 elements required for plant nutrition in balanced proportion, it is said to be fertile (Augusto et al., 2002; Oertly, 2008). The Rima River floodplain is annually flooded, and farmers who cultivate the floodplain are aware of soil quality change, post flood. However, knowing the quantity of the quality change and the spatial pattern is potentially beneficial for soil fertility management. Thus, this study assessed the effect of flood on the soil quality of the study area.

Materials and Methods

Study Area

The study area is located in the middle course of the Rima floodplain, south of Dundaye settlement in Wamakko Local Government Area of Sokoto State, covering 563 ha (Figure 1). The floodplain is an alluvial lowland of 250m average height above sea level. It is underlain by sedimentary rocks in the Iullmeden basin, extending from Mali, through Niger to Sokoto. The area is characterized by chalky limestones, calcareous mudstones and clay shales.

Located in the semi-arid area with prolonged dry season (Adeniyi, 1993; Umar, 2013), rainfall is highly seasonal and controlled by the irregular movement of the Inter-Tropical Discontinuity (ITD) and experienced during the relatively short but intense localized thunderstorm covering small areas. Prior to late 1960s and early 1970s, the mean annual rainfall varied from about 700mm in the northern part of the basin to about 1100mm in the southern part of the basin (Adeniyi, 1993). Today, and indeed, Sokoto-Rima basin is one of the few areas fingered for having more acute climate change impact in Nigeria (Odjugo, 2010; Umar, 2013). Daily minimum temperature falls below 170C while the maximum reaches 440C (Ifabiyi and Eniolorunda, 2012).

Drained by Rivers Rima and Sokoto, the floodplain is characterized by expansive width, high groundwater recharge and groundwater component, long time of concentration, long time to peak, and it is liable to flood due to its sinuous nature and the spherical and compact shape of the basin (Ifabiyi and Eniolorunda, 2012). The study area is characterized by the alluvial and aeolian deposits which have varying permeability because of their variable composition. Where they are composed of pure sand, their permeability is fairly good and so is their infiltration capacity. The water table approaches the ground surface. Availability of drinking water during the long dry season and high soil water retention which makes possible the extension of the growing season beyond the end of the rains explain why there is high settlement concentration around the floodplain (Adams, 1986; Swindell, 1986). The floodplain is perennially cultivated with rice in the wet season and onions, tobacco and bananas in the dry season which require intensive inputs of labour. The superficial deposits of the floodplain soils are enriched with huge manure inputs from local herd dungs kept in the villages or from the direct droppings by the nomadic cattle that graze on the uncultivated floodplain land areas especially in the dry season.

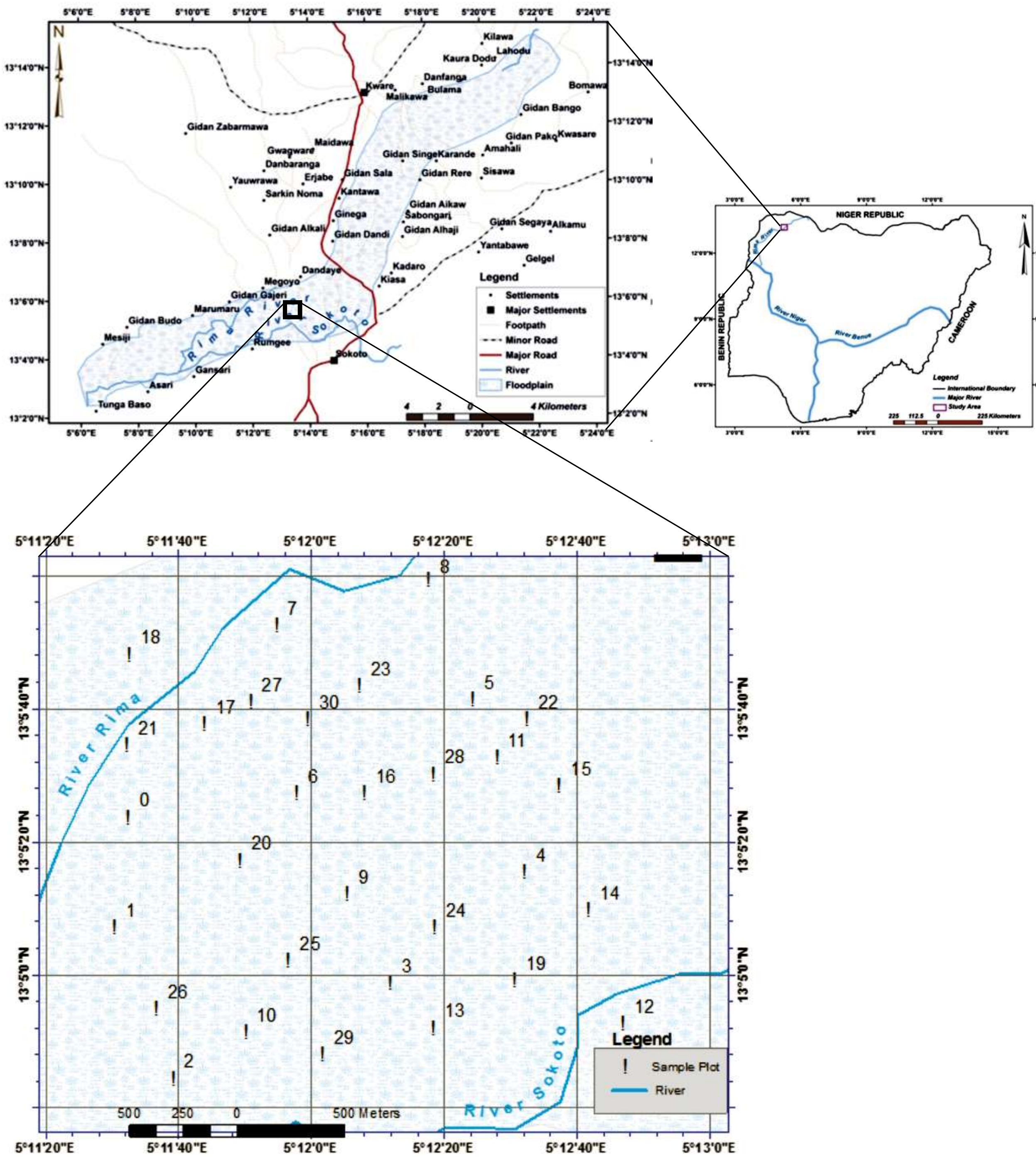

Figure 1: Study Area showing the soil sample locations

Soil Sampling and Treatment

Soil sampling was conducted in two different seasons of 2016: pre-flood season, when crops were already harvested (March/April), and post-flood season, when flood water had just receded (October/November). In each season, thirty-one plots (each being 15m by 15m) were selected at random for soil sampling, and in each plot, four points were randomly sampled at 0-30cm (Akinbile, 2012; Comte et al., 2012). The subsamples were bulked and homogenised for a plot, part of which was contained in a polythene bag, labelled and transported to the laboratory for test.

The samples were air-dried for 48hours, crushed and sieved with a 2-mm sieve. Tests for particle size, power of Hydrogen (pH), Soil Organic

Carbon (SOC), Total Nitrogen (TN), Potassium (K), Calcium (Ca), Magnesium (Mg) and Phosphorus (P) were conducted with the sieved samples. Particle size was determined by the Bouyoucos hydrometer method (Noma et al., 2011); pH was determined in water (1:1 soil-water ratio) (Vallejo et al., 2012), while SOC was determined using the Walkley-Black method (Noma et al., 2011). Total N was determined using Macro Kjeldahl method (Umar, 2011); K was determined by flame photometer, while Ca and Mg were determined by using Ethylenediaminetetraacetic acid (EDTA) (Noma et al., 2011). The available Phosphorus was determined using a spectrophotometer (Ibrahim, 2011).

Data Analysis

The mean and standard deviation of each soil property tested were calculated for each of the seasons, while statistical difference within the values of each soil property for each season was tested with the Chi-Square statistic at 95% confidence level. To examine the statistical difference in the tested variables between pre-flood and post-flood periods, Analysis of Variance (ANOVA) by General Linear Model (GLM) was used at 95% confidence level, processing all the variables at once. The overall effect of flood on the measured variables was tested with the Pillai's Trace at 95% confidence level. All analyses were carried out within the Statistical Package for Social Scientists (SPSS). Inverse Distance Weighting (IDW) was used to perform point interpolation for the sand, silt and clay in order to generate continuous surfaces necessary for textural mapping. IDW, being the commonest method of interpolation (Chakraborty and Sahooh, 2007), determines cell values using a linearly weighted combination of a set of sample points, with the weight being a function of inverse distance (Environment System Resource Institute, ESRI, 2014). System for Automated Geoscientific Analyses (SAGA) was used to combine the interpolated sand, silt and clay layers into soil texture maps for both seasons.

Results and Discussion

Soil Properties in the Pre-Flood and Post-Flood Seasons

Soil pH

The mean value of the soil pH is 6.03 with the Chi-Square result indicating that there is no significant difference ($P>0.05$) in the observations (Table 1). This value is rated as slightly acidic. Studies such as Noma (2002), Yakubu et al. (2008), Ibrahim (2011) and Noma (2011) have reported slight acidity for the study area. Slight acidity as observed may be attributable to production of H^+ ions and organic acids by soil microbes during organic matter (OM) decomposition (Havlin et al., 2005; Yakubu et al., 2008; Rao, 2012; Brady and Weil, 2013), suggesting that rate of OM decomposition is high in the study area post-flood. Yakubu et al. (2012) observed strong acidity in their study of the floodplain, attributing the phenomenon to intense leaching of basic cations or due to incessant uptake by plants. The implication of low pH is that it limits the availability of macro nutrients such as Ca, K, Mg, N and P in the soil (Foth, 1990; Joachim et al., 2008; Shagufta, 2012) and causes toxicity of Al, Co, Cu, Fe, Mn and Zn (Abubakari et al., 2012); hence, crop productivity may be affected. For the post-flood season, the soil pH only increased slightly from 6.03 to 6.07. There is no significant difference ($P>0.05$) in pH across the observations post-flood. Occurrence of flood is known to increase the pH of acid soils and decrease the pH of alkaline soils. Haapala et al. (1975) established a strong positive correlation between pH and water level of the River Kiiminkijoki, Finland. It was attribute partly to the acidifying effect of rain and melt water and abundance of peat in the area. Sun et al. (2007) also observed that soil pH increased with flood time in a contaminated soil in China. Lee et al. (2014) in their study noticed that pH concentration either remained the same or increased after flood. Although the pH values of both seasons did not statistically differ from each other ($P>0.05$), a slight increase is expected to boost the supply of major nutrients.

Soil Organic Carbon (SOC)

Table 1 shows that the SOC concentrations were low for the study area in both seasons. Within each season and between both seasons, SOC did not vary significantly ($P>0.05$) with an increase from 0.17 g/kg to 0.29 g/kg. SOC at both seasons had low ratings. Noma and Yakubu (2002), Noma et al. (2008), Yakubu et al. (2008) and Ibrahim (2011) have reported and classified the SOC of the study area as low. Factors attributed to low SOC in the study area include low organic manure due to near total removal of crop residues from the farmland, low vegetation cover, rapid mineralization due to high temperature and moisture conditions, bush burning and intensive cultivation. This can be reported for the pre-flood season. Although increase in SOC between both times was very slight, Lee et al. (2014) and Hossain et al. (2016) in their respective studies attributed increases in organic matter in the soil to plant residue deposition from flood. Thus, it may be right to suggest that plant and crop residues both from the upland and upper courses of the rivers were transported and deposited to the study area. However, this input might vary spatiotemporally depending on the strength and duration of flood, as Baldwin et al. (2013) and Saint-Laurent et al. (2016) discovered that the frequently flooded areas have significantly less SOC due to absence of ground litter which was a consequence of flood. OM is a major indicator of soil quality (Fallahzade and Hajabbasi, 2012); its adequacy is essential for maintaining and improving chemical fertility, soil porosity, infiltration capacity, moisture retention and resistance to erosion (Cerli et al.,2009). Therefore low SOC due to low OM will result in low productivity of the soil.

Table 1: Statistics of Soil Properties

Pre-Flood Season	Sample Size	Mean	Chi SQ Sig.	Post-Flood Season	Sample Size	Mean	Chi SQ Sig.	ANOVA Sig.
pH	31	6.03 ± 0.47	0.45	**pH**	31	6.07±0.65	0.88	0.79
SOC (g/kg)	31	0.17±0.07	0.72	**SOC** (g/kg)	31	0.29±0.12	0.41	0.00*
N (g/kg)	31	0.10±0.01	0.02*	**N (**g/kg)	31	0.07±0.01	0.60	0.00*
P (mg/kg)	31	0.92±0.06	0.95	**P (**mg/kg)	31	3.87±0.12	0.98	0.00*
Ca (mg/kg)	31	0.63±0.11	0.08	**Ca (**mg/kg)	31	0.87±0.16	0.22	0.00*
Mg (mg/kg)	31	0.68±0.17	0.00*	**Mg (**mg/kg)	31	0.40±0.12	0.53	0.00*
K (cmol/kg)	31	1.56±0.43	1.00	**K** (cmol/kg)	31	0.28±0.09	0.12	0.00*
% Sand	31	64.83±5.98	0.71	**% Sand**	31	59.57±9.17	0.22	0.01*
% Silt	31	21.45±4.05	0.49	**% Silt**	31	18.90±6.27	0.01*	0.06
% Clay	31	13.73±3.66	0.31	**% Clay**	31	21.5±4.87	0.00*	0.00*

*significant at 0.05 level

Soil Nitrogen (N)

The mean N concentration obtained before the flood was 0.10 g/kg, with significant difference ($P<0.05$) across the study area. However, the concentration decreased after flood to 0.07g/kg but without significant difference ($P> 0.05$) across the study area. The earlier concentration is rated as medium, while the latter is low (Umar, 2011). However, Noma et al. (2004), Noma and Gabasawa (2005) and Ibrahim (2011) have reported low levels of N in their respective studies of the study area. The authors attributed low N concentration to low SOC in the study area. Babalola et al. (2011) obtained higher concentrations than the critical limit in similar environments. Both authors also attributed the high N levels to high OM among other things. In this study, the observed high N level across the area may not be unconnected with the high frequency and degree of application of nitrogenous fertilizers such as NPK and Urea in the study area. Brady and Weil (2013) submitted that the application of fertilizer usually results in a much larger concentration of nitrogen ions. The reduction in N concentration after flood is significant ($P<0.05$) and likely a consequence of leaching and runoff (Johnston, 2001). A similar reduction of N after flood was obtained by Akpoveta et al. (2014) in some flooded farmlands in Asaba and Onitsha, Nigeria. N is a macronutrient meant for the building of plant's protein (Foth 1990; Flores and Tracy, 2012). Deficiency of N results in the slow vegetative growth of plant, which delays plant maturity and degrades crop quality (Brady and Weil, 2013).

Soil Available Phosphorus (P)

Results indicate that P level was generally low in the area in both seasons as the mean concentrations are 0.92mg/kg and 3.87mg/kg respectively. The observations of each season did not differ significantly (P> 0.05), but a significant increase (P<0.01) was recorded after flood. Low content of P in parent material has been attributed to low P level in the study area which is characteristic of semi-arid environments. However, Kolay (2013) attributed low P in soil to P fixation, especially in kaolinite which characterizes the soil of the area. Low organic matter can also account for low P (Havlin et al., 2012). Comte et al. (2012) also submitted that low P is characteristic of acidic and highly altered soil. Brady and Weil (2013) added that amount of P removed during harvest is far greater than amount supplied in fertilizer application especially in the sub-Saharan Africa. The significant increase in the P level post-flood, although still a low concentration, can partly be attributed to slight increase in the SOC concentration and the fact that denitrification process and uptake of Phosphorus are slow in flooded areas (Johnston, 2001; Pezeshki, 2001; Yanga et al., 2004; Sawyer, 2011; Bly, 2015). Sahrawat (2012) observed that rice farmlands benefited from improvement in the P concentration due to flood. This is likely the case in the study area as rice is one of the most cultivated crops in the floodplain. Increase in P concentration was also observed by Kalshetty et al. (2012), although this is not the case with Akpoveta et al. (2014) that reported a general reduction due to possible leaching. P enhances seed germination and early growth, stimulates blooming, enhances bud set, aids in-seed formation and hastens maturity (Foth, 1990; Tucker, 1999, Banerjee et al., 2012). Its deficiency can result in stunted plant growth, thereby reducing crop yield (Brady and Weil, 2013).

Soil Potassium (K)

The mean of K before the flood was 1.56 cmol/kg with no difference among the observations (P>0.05). This value reduced to 0.28 cmol/kg with the observations not significantly different (P> 0.05). The reduction in the K concentration after flood was significant (P<0.05), although the concentrations in both seasons were high (Omar, 2011). Noma et al. (2005) reported higher values in the range of 1.74 to 19.6 cmol/kg for the same floodplain. In an earlier study, Noma et al. (2004) had observed a value of 22 cmol/kg for some particular areas within the floodplain but submitted that K level was generally at tolerable limits. For adjacent upland soils, Noma and Yakubu (2002) observed values that range between 0.18 and 0.74 cmol/kg. Yakubu et al. (2008), while comparing upland and floodplain soils of the study area, observed higher K values in the latter than in the former. This was also the case in the finding of Igwe et al. (2008), in their study, that all potassium fractions showed an increasing amount from the upland towards the floodplain of river Niger. K is reportedly more available in wet than dry areas (Rehm and Schmitt, 2002; Grzebisz et al., 2012). A plausible reason for high K concentration is contained in the submission of Brady and Weil (2013) that soils of arid and semi-arid environments have sufficient weatherable potassium-contained minerals that can adequately supply potassium to the soil. Also, in this study area, application of K-fertilizer especially NPK is possibly another cause of high concentration of K. It can be safely assumed that the significant drop in the concentration of K after flood might be a consequence of leaching and runoff. K is the second most abundantly needed nutrient by plants for quality performance, however excessive K levels can supress Mg and Ca concentrations thereby causing soil nutrient imbalance (Shagufta, 2012; Halvin et al., 2012; Brady and Weil, 2013).

Soil Calcium (Ca)

Concentrations of Ca in the pre-flood and post-flood seasons were 0.63 cmol/kg and 0.87 cmol/kg, both of which are below the critical limit. In each case, the distribution did not vary significantly (P> 0.05), but flood resulted in significant increase in Ca level. However, these concentrations reflect the characteristic Ca level as previously reported by various studies. Yakubu et al. (2006) observed low levels of Ca in the Fadama lands of Sokoto Metropolis which is exclusive of (but close to) the study area. Noma and Gabasawa (2005) obtained values between 0.3 and 1.5 cmol/kg for the study area, while Noma et al. (2004) previously observed values between 0.5 and 6.0. Yakubu et al. (2003) observed a range between 1.2 to 5.0 cmol/kg, while Abdullahi et al. (2010) obtained a mean value of 3.68 for upland areas around the floodplain. In other floodplains of similar environments, Abu and Malgwi (2011) and Omar (2011) obtained moderate Ca levels. The low levels of Ca concentration in the study area are likely due to two factors. The first is the fact that the soil pH of the area is acidic in nature which could cause the deficiency of Ca (Foth, 1990; Horneck et al., 2011; Brady and Weil 2013). Secondly, the high concentration of K as observed in the study area is capable of supressing Ca (Shagufta, 2012; Halvin et al., 2012; Brady and Weil, 2013). The increase in Ca concentration is likely a result of the flood water salinity (McCauley, 2005; Ankidawa and Awhari, 2010). Plants use Ca in amounts second only to Nitrogen and potassium, but when Ca deficiency occurs, crop performance is reduced and normally harmless levels of other metals such as Mg, Zn, Mn and Al become toxic (Brady and Weil, 2013).

Soil Magnesium (Mg)

Findings show that Mg levels in the pre-flood and post-flood seasons were 0.68 cmol/kg and 0.40 cmol/kg respectively. Significant difference ($P<0.05$) existed in the earlier observations but the latter observations did not differ in concentration significantly ($P>0.05$). The mean Mg concentrations for both seasons are rated medium. Previous reports were either medium or high in the study area. Halvin et al. (2012) suggested that enrichment in Mg level could result from addition of Mg-contained fertilizer or through addition of dolomitic limestone. They further suggested that high levels of K^+, NH_4^+, and Al^{3+} could obstruct plant uptake of Mg thereby increasing its level. These and irrigation are highly suspected as factors of the observed phenomenon (Yakubu et al., 2006; Abu and Malgwi, 2011). Further, it was discovered that a significant reduction in the concentration of Mg occurred post-flood, which could be attributed to leaching and runoff effect. Mg is central to photosynthesis (Shagufta 2012; Brady and Weil, 2013), however excess concentration in soil can assist high Na in soil dispersion (Rengasamy et al., 1986).

Soil Texture

The particle sizes were interpolated for each season using IDW method (Figures 2 to 7). Figures 2, 4 and 6 were combined to generate the textural map (Figure 8) for the pre-flood season, while Figures 3, 5 and 7 were used to map the post-flood texture (Figure 9). Table 1 shows that the proportions of sand, silt and clay did not vary significantly ($P>0.05$) across the study area in the pre-flood period. Thus, the prevalent soil texture based on the USDA taxonomy is sandy loam. Noma and Yakubu (2002) classified the texture of the floodplain as loamy to sandy-loam to clay loam. Yakubu et al. (2008) observed loam to sandy-loam, while Yakubu et al. (2012) observed more divergent textural classes for the study area. Noma et al. (2004) and Noma et al. (2008) observed varied and unpredictable trend in textural classes spatially and across depth, attributing differences in deposition of different transported materials due to changes in the direction, flow and velocity of river water. With the exception of sand, Chi Square results indicated that silt and clay proportions varied significantly ($P<0.05$) among observations post flood. Also, there were reductions in the proportions of sand and silt but an increase in clay. The changes were significant for sand and clay but not for silt. On the whole, the area experienced a textural change from sandy loam to sandy-clay-loam. The textural change was consequent upon material deposition due to flood.

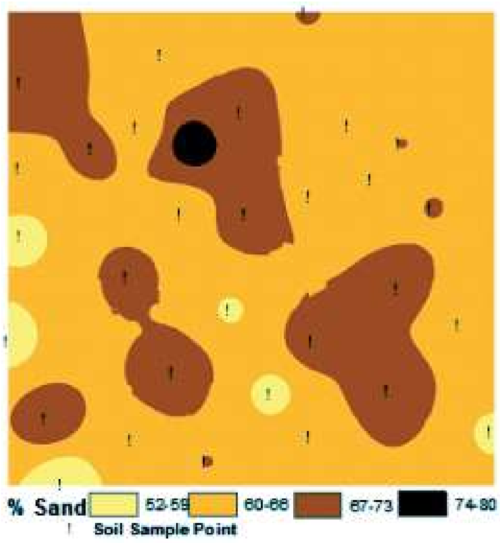

Figure 2: Sand pattern before 2016 flood

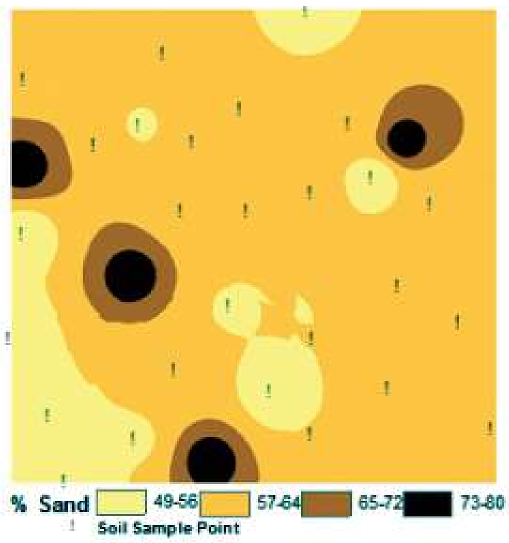

Figure 3: Sand pattern after 2016 flood

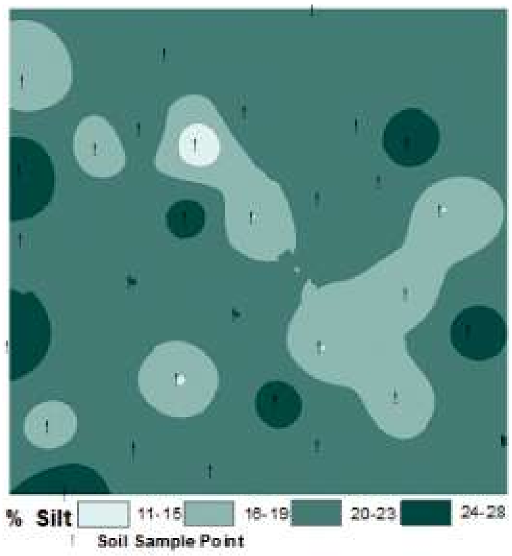

Figure 4: Silt before 2016 flood

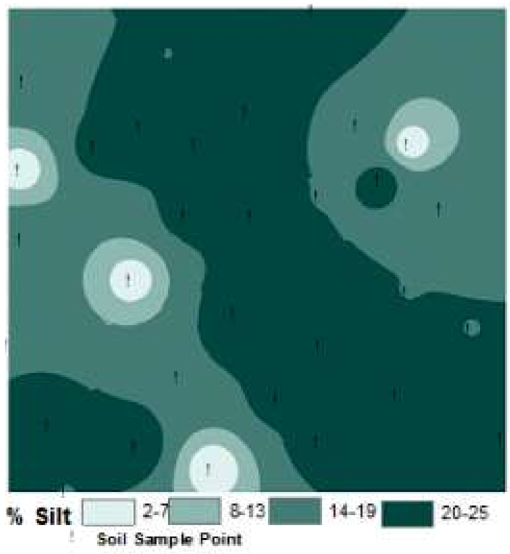

Figure 5: Silt after 2016 flood

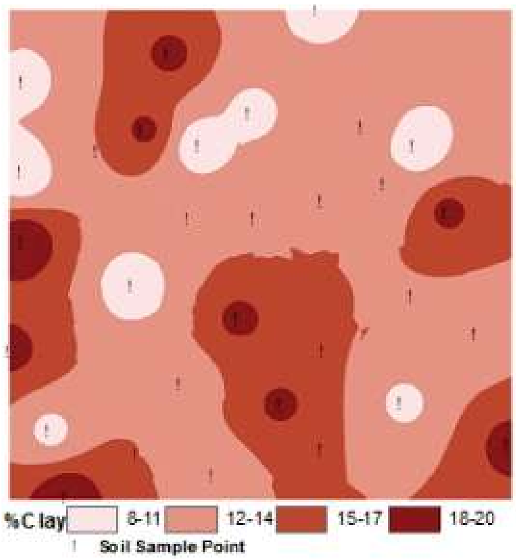

Figure 6: Clay before 2016 flood

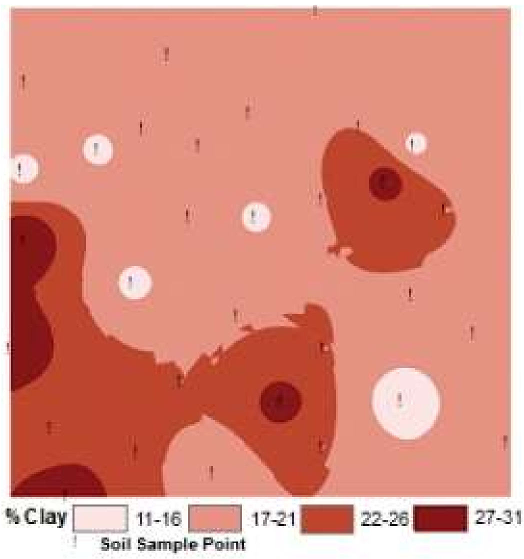

Figure 7: Clay after 2016 flood

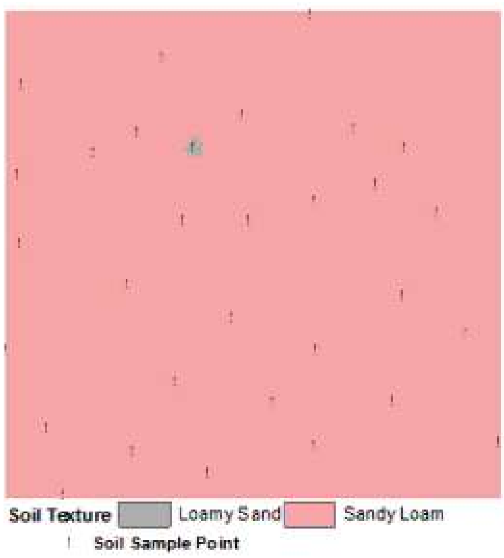

Figure 8: Soil Texture before 2016 flood

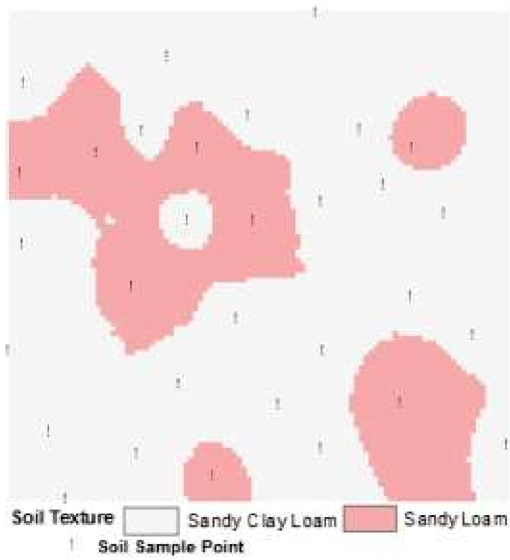

Figure 9: Soil Texture after 2016 flood

Conclusion and Recommendation

The Pillai's Trace obtained from the ANOVA test shows that the soil properties between both seasons changed significantly ($P<0.05$). Based on the results of this study, it is concluded that the flood of the 2016 effectively impacted on the soil properties. Thus, it is recommended that soil quality change be assessed annually for the floodplain for sustainable soil management. Future study should be extended to determining the effect in terms of change in soil properties but also in quality. This can be achieved by interpolating and integrating various soil properties relevant for soil fertility assessment.

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