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Spatial Distribution of Soil Cationic Micronutrients along Rainfall Gradient in Sorghum-Based Cropping System in Sudano-Sahelian Zone of Nigeria

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ABSTRACT: Mapping of soil fertility constraints is one of pre-requisite for sustainable agriculture to address the issues of low crop productivity in smallholder farms. This research was aimed at quantifying the degree of spatial variability of cationic micronutrients' constraints under sorghum-based cropping system along a rainfall gradient to develop appropriate data base for small holder farmers and to develop appropriate fertilizer recommendation. Twelve sorghum-based farms were selected through multistage sampling techniques based on isohytes of 50 mm interval from Kofa (950 mm) to Zango (400 mm) across the study area. Soil samples were collected from the farms and analyzed for cationic micronutrients using standard analytical methods. Descriptive statistics and geostatistical analyses were used to analyze the data generated. Results indicated that distribution of the cationic micronutrients varied significantly with their concentrations rated high (Zn = 2.1 to 35.6 mg/kg; Fe, Mn = 5.1 to 30.6 mg/kg and Cu = 1.0 to 6.8 mg/kg)showing only patches of medium (Zn = 1.0 to 2.0 mg/kg; Mn = 1.0 – 5.0 mg/kg and Cu = 0.2 to 1.0 mg/kg) and low (Zn = 0.51 to0.99 mg/kg and Fe) concentrations across the study area. The concentrations of all the micronutrients decreased with increasing rainfall except Cu which increased with increasing rainfall. The best fit semivariogram model for Zn was stable. The high spatial dependency observed for Zn and Cu recommends for developing a strategy for site specific fertilizer management taking into account the structural and random factors dominant in the study areas.

KEY WORDS: Spatial Distribution, Cationic Micronutrients, Rainfall Gradient, Sorghum-based cropping System.

I. INTRODUCTION

Food insecurity is one of the major problems affecting humanity in Sub-Saharan African (SSA) countries where the human population is about 646 million. This increased pressure on agricultural land which necessitated continuous cropping, thus bring about nutrients deficiency (Woperies*et al.*, 2005 and William Dar, 2013) and resulted in low yield crop production. Therefore, poor soil fertility is the main biophysical constraints affecting crop production in SSA. Also the amount and intensity of precipitation has a direct influence on crop yields and soil properties. Fatubarin and Olojugba (2014) observed that peak of rainfall as a season has profound effects on soil properties.
Sorghum is one of the most important staple food crops in Sub Saharan Africa including Nigeria, apart from food, the grains and biomass are used as livestock feed, fencing, thatching, alcoholic and non-alcoholic drinks, as well as baking and confectionary uses (FAOSTAT, 2012).
Cultivation of sorghum in Nigeria has continued to rise over the years particularly in the last decade with an estimated land area of about 66.5 million hectares annually and farmers yields have risen tremendously from about 3.8 - 4 .8 million metric tons of dry grains (NBS, 2017). The United State Department of Agriculture (USDA) estimated that by June 2017, the World Sorghum Production 2017/2018 will be 59.34 million metric tons. Sorghum Production last year was 63.08 million tons. This year 59.34 estimated million tons could represent a decrease of 3.74 million tons or a -5.93% in sorghum production around the globe. The sorghum production in Nigeria 2017/2018 estimates to be 6.5metric tons (FAO, 2015).

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. In Nigeria, soil fertility deterioration is the major problem of most smallholder farms and this is further aggravated by the low input of subsistence farming, and results to low yield in arable crop production particularly sorghum. With regards to this, soil fertility and productivity in the tropics and particularly in dry land areas continues to be a major concern to scientists and policy makers due to its direct implication for food security.

Accurate and reliable information on geo-statistical mapping may assist the smallholder farmers and other research institutes for proper land use management which could be useful for decision making on land use planning and soil fertility management strategies. Therefore, a research that aimed to bridge the gap by assessing the soil fertility constraints in relation to sorghum yield is highly imperative for smallholder farmers to survive and improve their livelihood.

II. SIGNIFICANCE OF THE STUDY

Monitoring concentrations of soil micronutrients as affected by rainfall distribution is highly imperative for smallholder farmers to survive and improve their livelihood. Precise and reliable information on geo-statistical mapping of these nutrients is much likely to helpthe farmers to increase sorghum yields for sustainable production in the study area.

III. METHODOLOGY

The study area is within Sudano-Sahelian zone of Nigeria located between the latitude 11^{o}0`0``N and 13$^{o}$0`0``N and Longitude of 8^{o} 0`0``and 9$^{0}$0`0``E (Figure 1) with an altitude of 481-500 m above sea level.

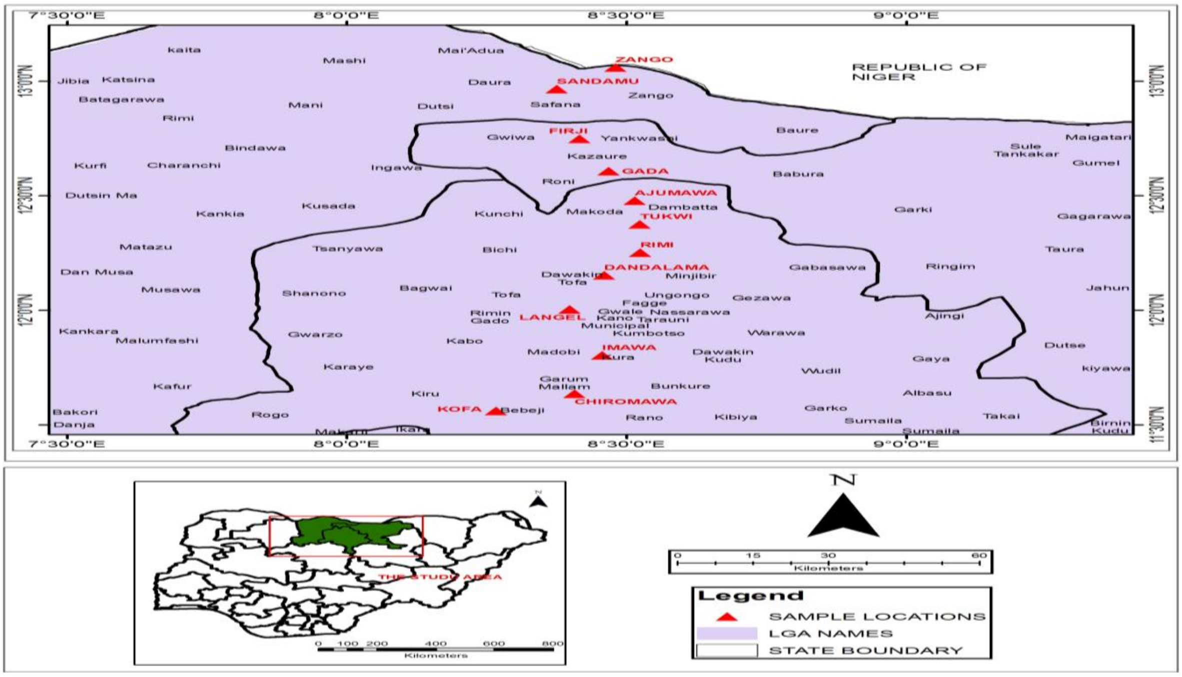

Figure1: Map of Transect Showing Sampling Communities

A. SOIL SAMPLING, PREPARATION AND ANALYTICAL PROCEDURES

Twelve (12) communities were selected along Kofa- Zangon Daura transect (Figure 1) of Sudano-Sahelian zone of Nigeria. The selection was based on 50 mm difference of rainfall (Figure 2). The farms were selected using multistage sampling technique. In each community, ten (10) farms of which sorghum grown ware selected using 10 km by 10 km sampling grid. In each farm, two meter quadrats were laid diagonally in order to capture variability (i.e. at four cardinal points and center). From each quadrat one soil sample was collected at depth of 0-20 cm using soil auger. The soil samples were mixed thoroughly and resampled using quartering process to obtain a composite soil sample representing each of five (5) quadrats.

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Therefore, one (1) composite soil sample was collected from each farm giving a total of ten (10) composite soil samples from ten identified farms in each community. Thus, one hundred and twenty (120) composite soil samples were collected from twelve communities and used for the research. The coordinates were recorded using global positioning system (GPS) receiver for the purpose of plotting spatial map on soil fertility of the study area.

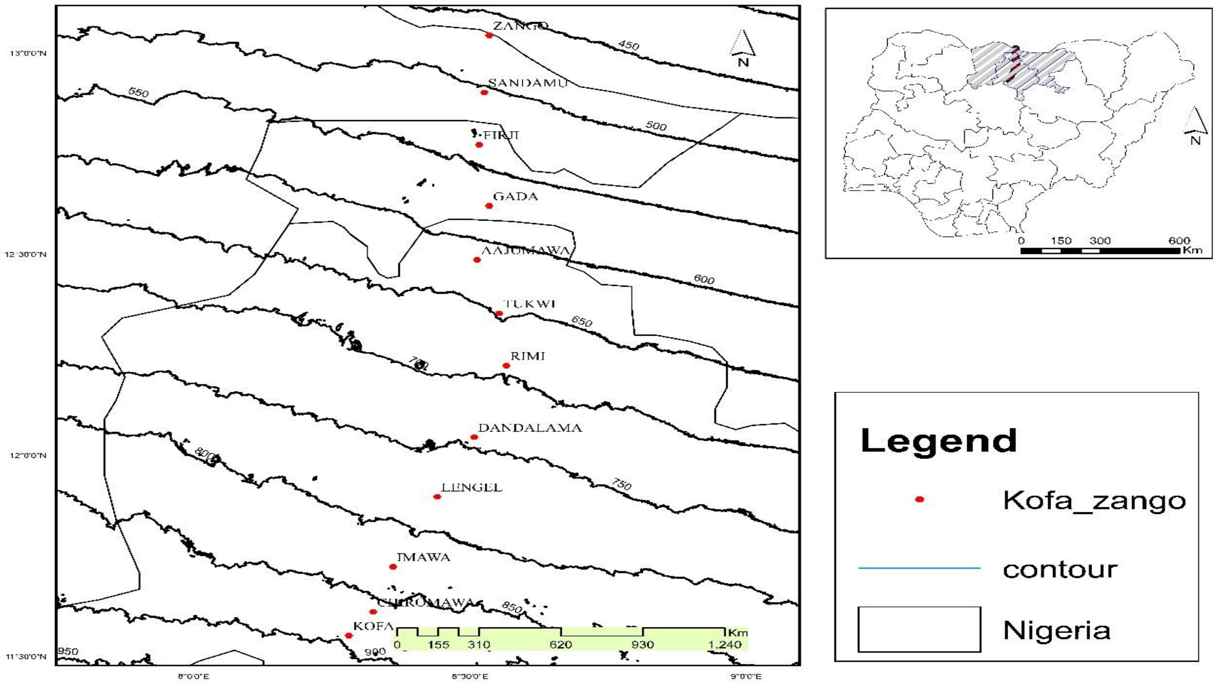

Figure 2: Map of Rainfall Gradient Showing the Isohyets

The soil samples were air-dried, crushed gently with porcelain pestle and mortar and then passed through 2 mm size sieve. The fine earth separated was stored in plastic bottles for laboratory analysis.

The soils samples were analyzed in the laboratory using standard laboratory procedures.

Soil particle size distribution, pH and electrical conductivity were determined using methods described by Boyoucos, 1962, Thomas, 1996 and Bower and Wilcox, 1965, while organic carbon, available phosphorus, exchangeable bases were estimated using procedures described by Walkley and Black (1934), Olsen (1965), Anderson and Ingram (1993), respectively. Total nitrogen was determined using micro-Kjeldahl digestion method (Bremma, 1996). Effective cation exchange capacity was determined using summation method.

Available Cu, Mn, Fe, and Zn were determined using hydrochloric acid extraction and absorption spectroscopy (Lindsey and Norvell, 1978).

B. STATISTICAL ANALYSIS

The data obtained was subjected to a series of statistical analysis ranging from descriptive statistics such as mean, maximum, minimum, standard deviation, CV, skewness, and Kurtosis to determine the degree of variability and normality of the data sets. Then, a geo-statistical analysis was performed using kriging interpolation to predict the spatial variability of soil fertility parameters along transect. Correlation analysis was used to determine the relationship between soil properties and rainfall distribution.

C. DESCRIPTIVE STATISTICS

The soil properties data obtained from the study area were subjected to descriptive statistics including mean, median, maximum, minimum, coefficient of variation, standard deviation skewness and kurtosis to estimate the variation

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between sampling locations and normality of dataset using version 15 GENSTAT and Kolmogorov- Smirnov test at 5% level of significance respectively.

D. GEO-STATISTICAL ANALYSIS

The geostatistical analysis was performed using the kriging interpolation technique within the spatial analyst extension module in ArcGIS 10.3 software package to determine the spatial dependency and spatial variability of soil properties. An interpolation technique called ordinary, simple and universal kriging was used to produce the spatial distribution of the soil parameters for the study area. The models of semivariograms such as stable, exponential and Gaussian were used on the basis of a goodness of model fit criterion. The data were checked for normality and transformed as appropriate. Spatial analyses and mapping of the classified micronutrients and PSD, were performed in a GIS environment and experimental semivariogram were calculated using equation(1):

$$Y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} ([Z(xi + h) - Z\ (xi)]^2) \quad \text{equation 1}$$

Where h is the semivariance for interval class, N(h) is the number of pairs separation by lag distance (separation distance between sample portions), Z(Xi) is measured variable at spatial location at spatial location i, and Z(xi + h) is the measured variable at spatial location i+h.
The spatial distribution maps and status of the micronutrients were designed using kriging interpolation through semivariogram package. A Semivariogram was used to compute and determine the spatially dependent variance of soil properties. The experimental data were fitted to various semivariogram models ranging from exponential, Stable and Gaussian, and the best model was selected based on the fit. Using the model semivariogram, basic spatial parameters such as nugget (Co), partial sill (C), range (A) and sill (C + C0) was calculated. Nugget is the variance at zero distance, the sill is the lag distance between measurements at which one value for a variable does not influence neighboring values and range is the distance at which values of one variable become spatially independent of another (Lapez-Granados *et al.*, 2002).
Different classes of spatial dependence for the soil variables were evaluated by the ratio between the nugget and the sill. For the ratio lower than 25%, the variable was considered to be strongly spatial dependent, or strongly distributed in patches; For the ratio greater than 25%, the soil variable was considered moderately spatial dependent; and for the ratio higher than 75%, variable was considered as weak spatially dependent variable, or if the slope of the semivariogram was close to zero, the soil variable was considered non-spatially correlated (pure nugget) (Cambardella*et al.*, 1994). ArcGIS was used to delineate filled contour maps for some soil fertility parameters.
Several interpolations techniques and models were fitted into semivariogram to select the best model that will bring positive nugget to minimize estimation error.

IV. EXPERIMENTAL RESULTS

A. DESCRIPTIVE STATISTICS

Table 1 presents the descriptive analysis of soil cationic micronutrients in the study area.High variability of Zn content was observed with CV and mean value of 95.18%and 6.77 mg/kg, respectively. The skewness was 2.17 and kurtosis was 5.52, thus indicating positive skewness and kurtosis. Similarly, the Fe content showed strong variability with CV of 82.94%, mean value of 11.96 mg/kg, minimum value of 0.31 mg/kg and maximum value of 39.24 mg/kg. Furthermore, high variability of manganese contentwas observed with a CV of 52.03%, with a mean value of 12.3 mg/kg. The skewness positive value was 0.77 while kurtosis negative value of -0.82. Similar result was recorded for Cu with high variation (CV = 46.90%) with a mean value of 2.20 mg/kg.All the micronutrients failed to pass normality test because the values deviated from the normal range.
The high variability observed in terms of concentration of the micronutrients may be due to differences in management practices such as tillage and fertilizer application in the different communities studied (Wade, 2017).

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Table 1: Descriptive Analysis of Soil Cationic Micronutrients of Study Area

Micronutrients	No.	Min.	Max.	Mean	CV	Sk.	Kurt.	Norm.
Zn (mg/kg)	120	0.51	36.65	6.77	95.18	2.17	5.52	No
Fe (mg/kg)	120	0.31	39.24	11.96	82.94	1.09	0.26	No
Mn (mg/kg)	120	26.56	30.86	12.3	52.03	0.77	-0.82	No
Cu (mg/kg)	120	0.06	6.83	2.20	46.90	0.77	2.18	No

Zn(Zinc),Fe(Iron),Mn(Manganese)Cu(Copper),No.(Numberofsample),Min(Minimum),Max(Maximum), CV(Coefficient of variability), Sk.(Skewnesses), Kurt.(Kurtosis), Norm.(Normality).

B. GEOSTATISTICAL STUDIES

Table 2 shows thesemivariogram of the soil micronutrients in the study area. Zinc and Cu have strong spatial dependency ratio of zero (Table 2). This may be attributed to pedogenic factors. However, Fe and Mn were found to show moderate dependency ratio with a value of 34% and 28% respectively. This is probably as a result of interplay between pedogenic and management factors. In addition, the coefficient of determination (R^2) between observed and predicted soil micronutrients was found to be good because all the micronutrients have values around one (Table 2).
Table 2: Semivariogram of Soil Micronutrients of the Study Area

Micronutrient	Statistical Model	Nugget (Co)	Partial Sill (C)	Sill Co + C	Range (A/km)	SDR (N:S Ratio %)	SDC	R^2	Interpolation Techniques
Zn (mg/kg)	Stable	0	0.57	0.57	0.1	0	Strong	0.99	Ordinary
Fe (mg/kg)	Exponential	0.39	0.77	1.16	0.16	34	Moderate	0.80	Ordinary
Mn (mg/kg)	Exponential	0.086	0.21	0.29	0.14	28	Moderate	0.84	Ordinary
Cu (mg/kg)	Stable	0	0.32	0.32	0.17	0	Strong	0.99	Ordinary

C_o (Nugett effect), C_1(Structural variance), r^2(Coefficient of determination), SDR(Spatial Dependency Ratio), SDC (Spatial Dependency Class).

C. SPATIAL DISTRIBUTION OF ZN, FE, MN AND CU AS AFFECTED BY RAINFALL GRADIENT

Table 3 shows the relationship between soil cationic micronutrients and rainfall gradients in the study area. Zinc, Fe, and Mn were highly negatively correlated with northerly latitude with r values of -0.523**, -0.513** and -0.533** respectively (Table 3). This implies that the content of Zn, Fe, and Mn were decreased with increase in rainfall(Table 3). Contrary to the trend of Zn, Fe, and Mn, high positive correlation between Cu and rainfall was observed ($r = -0.316^{**}$) indicating that the Cu increased with increase in rainfalls indicated in Table 3.

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Table 3: Pearson Correlation (r) Between Soil Cationic Micronutrients and Rainfall Gradients

Micronutrient	Correlation Coefficient(r)values
Zn	-0.523**
Cu	0 .316**
Fe	-0.513**
Mn	-0.533**

*Significance at 5% Level of Probability, ** Significance at 1% Level of Probability

Spatial distributions of Zn, Fe, Mn and Cu are presented in Figures 3, 4, 5 and 6 respectively. Soil fertility rating of Esu (1991), Landon (1991) and Malgwi (2013) were used in interpreting the results obtained in the study area.
Iron and Mn are moderately spatial dependent variables (Table 3). This implies that theirvariation may be attributable to interplay between pedogenic and anthropogenic factors. However, the trend map of Fe concentration indicated high amount of Fe with small patches of low concentrations around Chiromawa(Figure 4). This implies that the Fe content increases with decrease in northerly latitude which might be due to Fe-bearing minerals viz., hematite and goethite, and redox reaction in these soils (Mustaqua*et al.*, 2010);Vijaya Kumar *et al.*, 2013). Furthermore, high content of Mn was observed indicating increase with decrease in rainfall as indicated in Figure 2. Nevertheless, small portion of Mn was obtained in Dandalama, Rimi, and some part of Sandamu. This could be attributed to differences in pH, organic matter content, texture and drainage pattern and Mn bearing minerals in the parent material. Unlike Fe and Mn, strong spatial dependent ratios were observed in Zinc and Cu as presented in Table 3 indicating that the variation was from pedogenic factors.
Moreover,high concentration of Zn content was observed in Kofa, Chiromawa, and Imawa while the least concentration was obtained in Sandamu andZango as presented in figure 3. This shows that Zn content was increased with decrease in rainfall gradient (Figure 2) hence, this may be probably due to pedogenic processes and complexion with organic matter, subsequently leading to chelating of Zn, P, and pH in the soil (Verma*et al.*, 2005). The trend map of copper indicated high concentration ofCu and decreases with increase in rainfall gradient (Table 4 and figure 10). This result has contradicted the findings of Shehu*et al.,* (2015) who reported low content of Cu obtained in Bunkure and Shanono, Sudan savanna zone of Nigeria. The reason of the high Cu concentration might be due to high biological activities in the soil and chelating effect (Singh *et al.*, 2007 and Jibhakate*et al.*, 2009). The general increase of the concentrations of Zn, Fe and Mn may not be unconnected with lack of leaching due to low rainfall in the study area.

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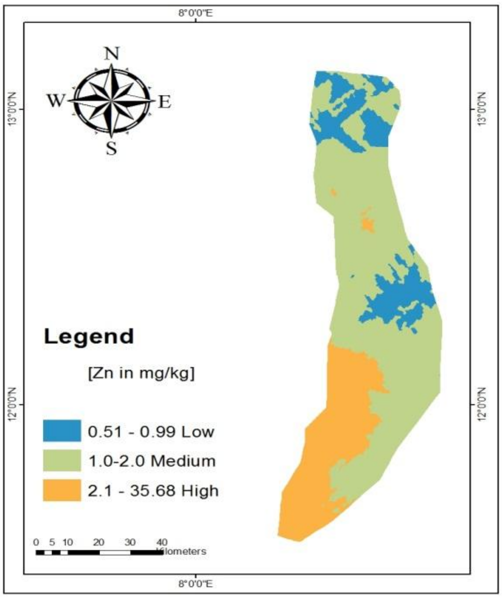

Figure 3:Spatial Distribution of Zn

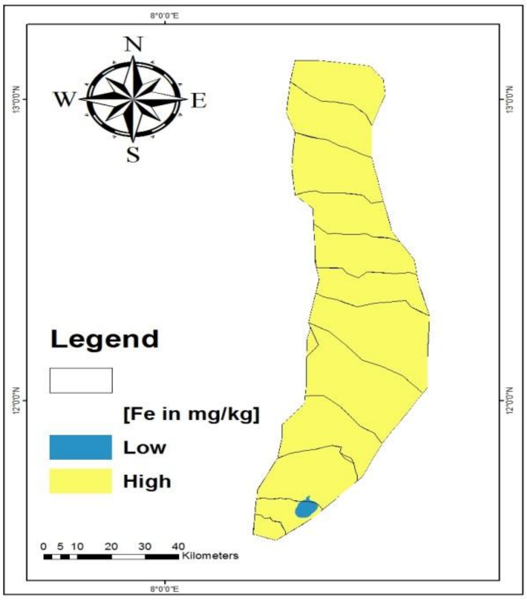

Figure 4:Spatial Distribution of Fe

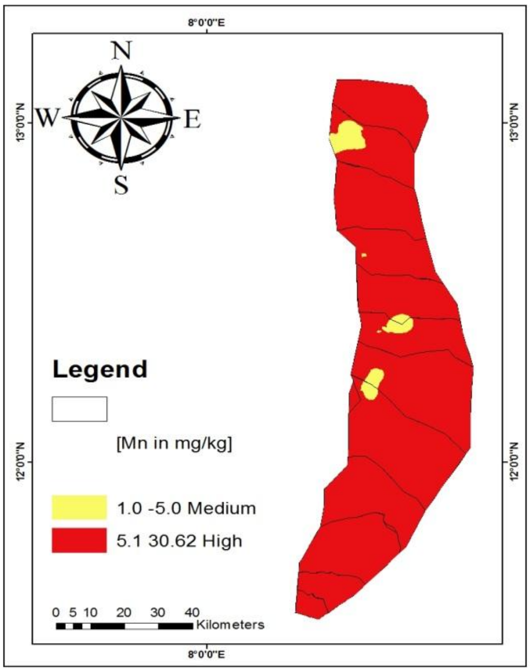

Figure 5: Spatial Distribution of Mn

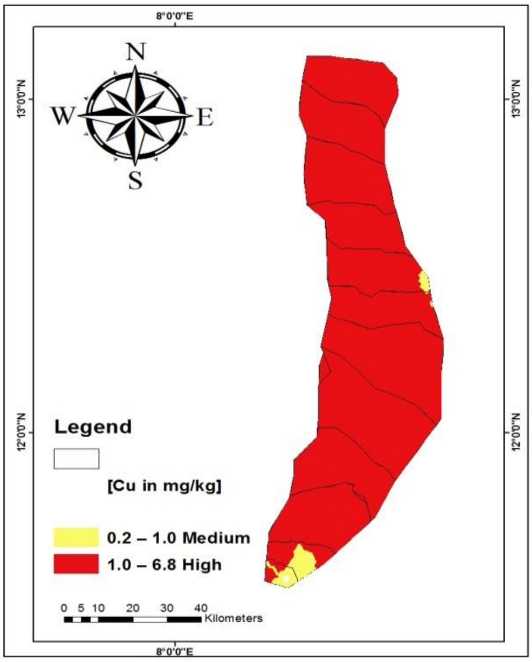

Figure 6: Spatial Distribution of Cu

V. CONCLUSION AND FUTURE WORK

The distribution of the cationic micronutrients studied (Zn, Fe, Mn and Cu)varied significantly with their concentrations rated high showing only patches of medium (Zn, Mn and Cu) and low (Zn and Fe) concentrations across the study area. The concentrations of all the micronutrients decreased with increasing rainfall except Cu which increased with increasing rainfall.The best fit semivariogram model for Zn was stable.

The high spatial dependency observed for Zn and Cu recommends for developing a strategy for site specific fertilizer management taking into account the structural and random factors dominant in the study areas. The response of soil physico-chemical properties to rainfall gradients in the study area needs to be evaluated for further mapping.

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