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Spatial Distribution and Assessment of Selected Physiochemical Parameters of Soils Using GIS Techniques in Bunkure Kano State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MA designed the study, performed the data analysis and interpreted the result and the first draft of the manuscript. Author DNJ created the topic and supervised the work. Author AKU checked the analyses of the study. Authors GKA and MUM checked the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

In recent years thematic mapping has undergone a drastic change due to advances in technology, as the result of this different aspects of field of study begin to emerge while others has been transformed. Soil mapping is an example of these aspects. Soil information is one of the areas that needed a robust data for study. The application of GIS in soil analysis transformed the conventional approach, being simpler and accurate in terms of analysis and the production of different maps in theme and layers for soil information. This paper analyzed the distribution of soil physicochemical parameters in Bunkure. Data were collected using GPS (Garmin 76csx model). Grid sampling technique were adopted, 51 soil samples were collected from the depth of 30 cm. Standard laboratory analysis were used for analysis, selected parameters for the purpose of this study (pH,

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N, P, K, Ca, Mg, Na, OM, OC (organic matter) and EC). The data were transformed into GIS environment using Inverse Distance Weighted (IDW) interpolation model in the Arc GIS 10.1 version. The result shows that the spatial distribution of pH ranges from 2.90 – 9.66, while Mg has moderate values of 0.04-0.93 ppm. The area is generally considered to have low OC, Na, Ca, and OM with < 2, 0.01-0.23, 1.05-9.12ppm, and 0.02-1.6% respectively. While values within the medium range are N, CEC and K with 0.02-0.96%, 2.09-7.75meq/100 g and 0.01 1.00 (cmol/kg), while EC with 0.05-50.92. The study concludes that the area is low in fertility and there is evidence of salinity development in the western parts of the study area which is the irrigated site. The study therefore recommends for proper management during fertilizer application and the need for data storage of soil information at regular interval which will help the policy makers in planning for sustainable agriculture.

Keywords: Physicochemical parameters; soil; GIS; inverse distance weighted.

1. INTRODUCTION

Nigeria, beign the largest and most populated African country, has rapid demographic growth, most of them depend heavingly on agriculture. In addition Nigeria features predominantly in nutrient depletion scenarios [1,2], and among many factors limiting agricultural development in the country is the lack of sufficient information on soils and their characteristics [3].

The scenario of low fertility in the region leads to low output which has been estimated by [43] in 38 sub Saharan countries, which shows that most of the important nutrients were lost in the area which was projected to increase the annual nutrient depletion. [4] claimed that the sub Saharan African countries are losing not less than 60-100 kg/ha/year (World Bank, 2003), and there is a relationship between soil nutrient depletion and food insecurity which indicated less less improvement to some crops [5].

[6] lamented that most of the crops cultivated in this region (sub Saharan African countries) like rice, millet and wheat have a high demand for nutrients. These crops require both the major nutrients (N, P and K) and the secondary nutrients (S, Mg, Ca, B, Fe, Cl, Cu etc.) in adequate amount to ensure good root establishment, vigorous and healthy growth and increased yields. While [7] ascertained that plant growth may be retarded because these elements are actually lacking in the soil, they become available too slowly, or they are not adequately balanced by other nutrients and most of these element are needed in relatively large quantities.

Soil information on physiochemical properties helps the farmers to manage their farmlands effectively [2]. Lamented that Geographic Information System (GIS) is one of the tool that is capable of analyzing, storing and displaying information. Therefore, applying GIS in the determination of soil information provide fundamental information to support in decision making on farmlands to be able to reduce problems caused by improper management. In recent years, there has been increasing interest in integrating GIS with Multi-Criteria Decision (MCD) analysis techniques for spatial planning and management [8-12].

Interpolation is one aspect of spatial analysis that is used in GIS which is applied for soil analysis. With Inverse Distance Weighted (IDW) one can control the significance of known points on the interpolated values based on their distance from the output point. This could be use to determine the distribution of a continuous data, phenomenon like rainfall, temperature, humidity, soil or distribution soil properties [13]. While, [14] found both kriging and IDW useful in analyzing soil parameters.

[15] Applied (IDW) for analyzing the soil chemical and physical parameters for different crops. Subsequently all of them were integrated using a Multi Criteria Decision making and GIS to generate the land suitability maps for various crops. Season cropping patterns maps were developed by integrating crop suitability maps for the winter and summer seasons separately. The result of the distribution shows a better analysis than the conventional methods.

The main objective of this study is thus to assess the spatial distribution of the some selected soil physicochemical parameters in Bunkure of Kano State as it implies to suitability of the soil for crop production.

2. STUDY AREA

Bunkure LGA is located between Latitude 11º34' 02''N to Latitude 11º46' 05''N of the Equator and between Longitude 8º 26' 36''E to Longitude 8º46' 43''E of the Prime Meridian. The study area comprises of fifteen wards (15) with an aerial extent of 9911.22 ha, and is bordered with Dawakin kudu and Kura LGAs by the North, Wudil and Garko LGAs by the East while Kibiya at the South Western part of the study area (see Fig. 1).

The subsistence rainfed farming is the most important economic activity in the region where intensification of small scale agriculture is the highest in the whole Northern Nigeria [16]. The area is dominated by farmed parkland with low nutrient status. There was also absence of fallow as farmers owned an average of two farms making a total holding of 1 hectare per household of about 10 persons. Farm resedues were consumed by livestock, this shows that most important option left to the farmers in order to sustain the low soil nutrient status is the application of fertilizer [17,18].

The area is one of the intensive cropping zones in the region [19,20] Yet, experiencing low soil nutrient as lamented by [21] in [22] revealed low fertility of soils of the area is well below critical levels of P and K. Low clay content of 11% on average translated into low availability of the important plant nutrients N, P, and K. [23] revealed low nutrient along the channels while, [24] shows a declined in the physical quality of the soil due to irrigation.

The region experiences four distinct seasons, Hot and dry season (*Rani),* Warm and wet season (*Damina),* Warm and dry season (*Kaka)* and Cool and dry season *(Bazara)* closely associated with the movement of the Intertropical Discontinuity (ITD). The mean annual Rainfall is about 884 mm varying greatly from the northern and southern parts of the area. The weather and climate of the area play a great role on the agricultural practices and are favorable to large scale cultivation of cereals, groundnuts, beans and vegetables. The socioeconomic activities of the people are also closely linked with the seasons, with crop production dominating during the wet season and off-farm activities dominating during the dry season while some engaged in irrigation activities [25,26] in 4. While, [27] described the area as the Kano Plain, consists of the following morphologica1 units: an upland plain.

Bunkure is within the Hydromorphic soils that tend to occur throughout the area [23]. Consequently, the Netherlands Development Company [28] found out in the area: a floodplain is flanked by a low terrace, a high terrace separated from the low terrace by a steep wall, and an upland plain, also separated from the high terrace by a steep wall. Thus from the upland plain to the river channel, there are three steep units 3 to 4 meters high and up to 60^o steep which encourage rapid runoff, in spite of the gentle slopes (1º to 2º) on the terraces [29].

3. FIELD AND LABORATORY METHODS

3.1 Field Work and Sample Collection

Grid cells of 1500 x 1500 meters (Fig. 2) were prepared on the base map for sampling [30]. Fifty one (51) soil samples were identified and collected in the field using the USDA Soil Survey Manual [31]. At each soil site, a GPS (Global Position Systems, Garmin 76x model) reading was used in taking the coordinates. The field equipments and tools that were used in collecting the soil samples includes the soil auger, Munsell color chart [32]. 30 meters measuring tape, pH, EC kits and GPS. Soil observations were made according to different soil units. The base map of the area was used in each soil site and observation includes a description of sites which were recorded in the field record data form (Database).

3.2 Laboratory Analysis

The samples were taken to the laboratory, air dried and gently crushed with porcelain pestle and mortar; and then passed through a 2mm sieve to remove coarse fragments. The sieved samples were analysed for the different physiochemical parameters. Soil portion of grain size of <2 mm collected were analysed. Particle size distribution was determined using hydrometer method [33] Sand, silt and clay were determined by dispersing the soil samples in 5% calgon (sodium hexametaphosphate) solution. The dispersed samples were shaken on a reciprocating shaker after which particle size distribution was determined with the aid of Bouyoucous hydrometer at progressive time intervals. The textural classes were determined with the aid of USDA textural triangle.

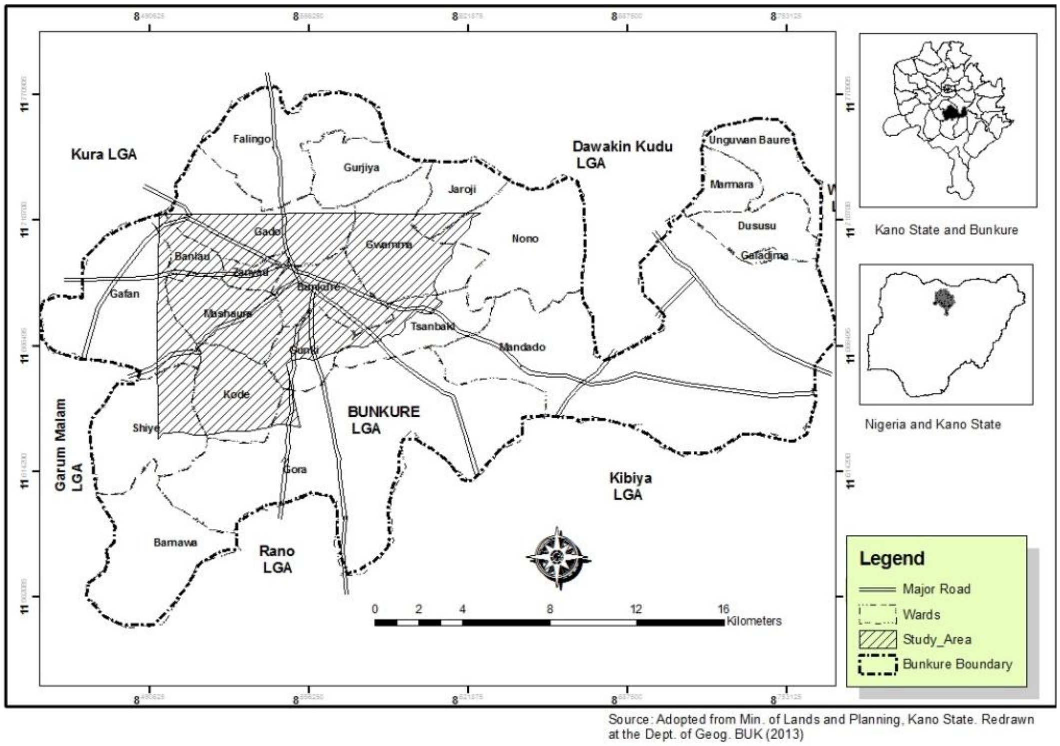

Fig. 1. Map showing the location of the study area

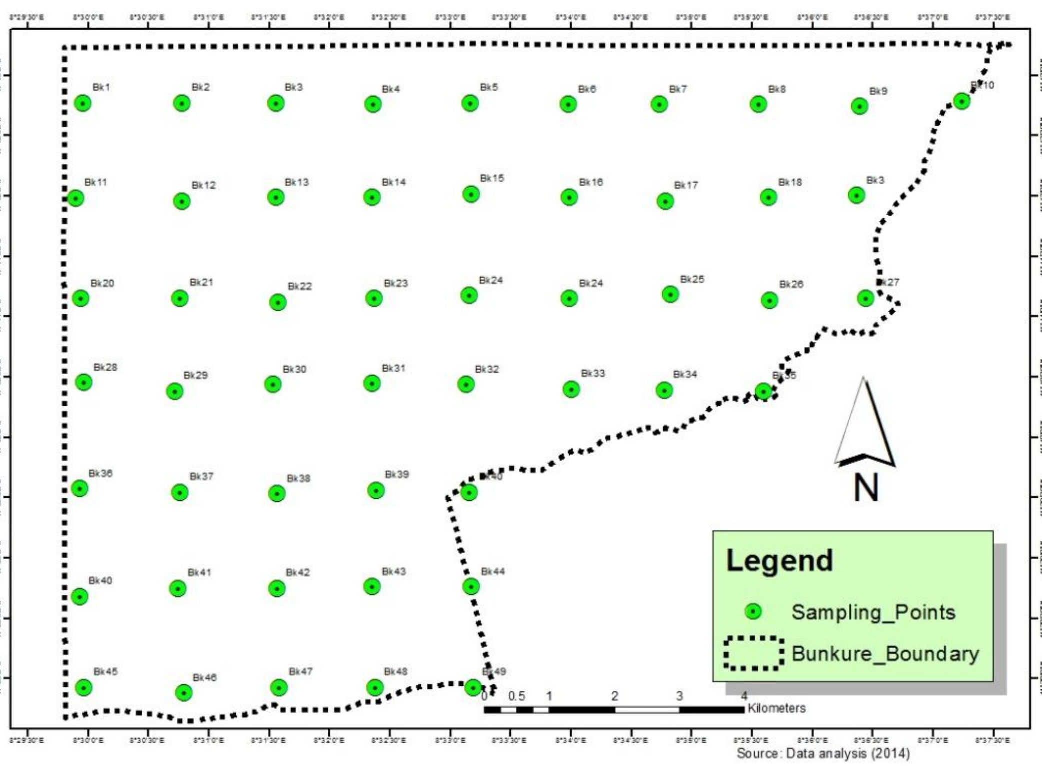

Fig. 2. Grid sampling points

The soil pH was determined both in water and 0.01M $CaCl_2$ solution, using a soil to solution ratio of 1:2.5 [34]. On equilibration, pH reading was taken with a glass electrode on a Pye-Unicam model 290mk pH meter. Delta pH (dpH) values were determined. The Walkley–Black wet digestion method was used to determine the organic carbon content of the soil samples [35]. Total nitrogen was determined using the macro – kjedhal method. Soil available phosphorus was determined using the Bray I method calorimetrically. Electrical Conductivity of the saturated paste extract of 1:2.5 soils to water ration were determine using a rheostat, Wheat-stone bridge model at 25ºC [36].

Exchangeable Ca, mg, Na and K were extracted with 1m ammonium acetate (1M NH_4OAc) solution buffered at pH 7.0 as described by [37]. Potassium and sodium in the extract were read on a Gallen Kamp flame Analyzer. The extracts were diluted two times with the addition of 2ml of 6.5% Lanthanum chloride solution to prevent ionic interference before Ca and Mg was read. The Ca and Mg were read on a pye unicam model SP 192 atomic absorption spectrophotometer (AAS) at 423 and 285nm wavelength respectively. The sum of Ca, Mg, Na, and K gave total exchangeable bases [2].

The soils were leached with 1m KCl solution and Exchange acidity (Al+H) in the 1m KCl extract was determined by titration with 0.1m sodium hydroxide solution as described by [37]. Cation Exchange Capacity (CEC) of the soil were determine with 1m NH_4OAc (1m ammonium acetate), buffered at pH 7.0 [38]. The excess acetate was removed by repeated washing with alcohol. The absorbed ammonium ions were displace with 10% sodium chloride (pH 2.5) and determined by the Kjeldahl procedure [39].

3.3 GIS Analysis

The laboratory results were entered into the Microsoft Excel application with their respective coordinates (Latitude and Longitude) and imported into GIS environment in order to analyse the spatial distribution of the selected parameters in the area. Different thematic maps (layers) were generated for each of the parameters using Inverse Distance Weighted (IDW) interpolation in the Arc GIS 10.1 software according to [40]. The IDW interprets spatial autocorrelation in an accurate manner [41]. A surface created with IDW will not exceed the known value range or pass through any of the sample points. IDW is a good interpolator for phenomena whose distribution is strongly correlated with distance. One potential advantage of IDW is that it gives explicit control over the influence of distance; an advantage over Spline or Kriging methods [15] each parameters were reclassified and converted into raster format.

4. SPATIAL DISTRIBUTION OF PHYSICO-CHEMICAL PARAMETERS

Table 1 showing the summary of the laboratory analysis, it indicated that pH (Fig. 3) values ranging between 2.90 – 4.67 which is extremely acidic according to [42] possibly toxic to some crop and is likely to have excess of some trace elements like Zn and Fe, from the analysis this occurs in a small portion of the study area especially the irrigated areas. While values that ranges from 4.67–6.43 which is extremely to slightly acidic dominated the area for about 65% and this is within the expectable values for most of the cereal crop. Values within 6.43–8.20 are slightly acidic, neutral and moderately alkaline have occurred to mostly areas that have high water retention capacity and poorly drained in the area and this is likely to have a decreasing availability of some trace elements.

The pH of 8.20 – 9.66 are moderately to very strong alkaline soils though, is dominating a smaller portion in the area and in this case there is likely to Ca and Mg unavailable and may be toxic to most crops as stated.

The Phosphorus (P) in Fig. 4 shows that the values are between 0.05–2.71, 2.71–3.10 ppm and 3.10–3.58 ppm in the area which indicated a low value and this is mostly needed for cereal crops (Cook, 1976). The range of 7.75 is moderate which occupied part of the northern and southern tips in the study area and is good for cultivation of Tomato and Cotton (London, 1988). While, Fig. 12 shows that Organic Carbon (OC) in the area were classified according to [1] for the purpose of this study which indicated values that are less than 2 in OC is said to be very low and this is an indication of the whole area to having a very low organic carbon.

The analysis of the exchangeable sodium (Na) in Fig. 13 shows that the whole values ranging from 0.01 to 0.23 is within the very low threshold which shows that values between 2–3 maybe more suitable criterion for distinguishing sodic soils, therefore the whole area under study is dominated with very low Na (Table 1), this element may be utilized by some plant as a partial substitute for Potassium (K) [43].

Fig. 9 shows the distribution of Nitrogen (N) with value ranging from 0.02%–0.22% which was low to very low [1]. The value between 0.22–0.50 is within the medium range, while the value of 0.96% is very high for N, the result of the analysis indicated that the area is concentrated in the medium range. The higher value in the area is likely as the result of soil management (the use of animal dung). Animal dung increased soil nutrient (NPK by 2.8, 0.6 and 2.4 percent respectively) as reported by [44].

Magnesium (Mg) is one of the exchangeable bases that are needed in the soil for plant development. The analysis in Fig. 10 shows that values ranging from 0.04 – 0.34 is within the low values stated by [43] while the range of 0.34 – 0.5 is within the medium and greater than 0.5 is high. Therefore, the dominant range is within 0.63 – 0.93 this is an indication that the area is suitable for most of the cereal crops.

The availability of calcium (Ca) varies from soil to soil, however Ca deficiency as a plant nutrient occurring in soil of low pH values of 5.5 or less [45] From the analysis in Fig. 5 shows that value ranges from 1.05 – 9.12 ppm which is an indication that the distribution of Ca is very low in the area and Ca deficiencies are reported for some leguminous crop at value < 120 ppm [43] and cotton is known to have a high Ca requirement.

The CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil [46] The analysis indicated that the values ranges from 2.09 to 7.75 meq/100 g from low to medium with an the mean value of 7.25 there is concentration of this elements at the middle of the study area (Fig. 6). The [47,48] CEC value in the top 30 cm of soil for satisfactory favourable lower value than those should be highlighted in land suitability classification. Any CEC of < 4 meq/100 g soil indicate a degree of infertility normally unsuitable for agriculture although rice is tolerance of slightly lower value.

The classification of EC in the area was based [47] which stated that the critical value for saline soils should be within 0–2 salinity are negligible excepted for most sensitive plant. The result of this analysis in Fig. 7 indicated that the range is between 0.05 to 50.92 with the mean value of 7.93 ds/m. Values from 4.63–8.22 are slightly saline, yield of many crops restricted while 8–15 moderately saline only tolerant crops yield satisfactorily and greater than 15 is strongly saline. In this case tolerant crop yield satisfactorily. The result of the distribution indicates that the whole area is affected with salinity with the concentration at the western part of the area.

The result of Potassium (K) in the area range between 0.01–1.00 (cmol/kg) with the mean value of 0.20 which has been stated by [1,25,43,49] to be medium and there are concentration within the central area of the study site (Fig. 8). Organic Matter (OM) ranging between 0.02% - 1.6% with a mean value of 0.38% (Fig. 11) from very low to low, however the distribution of OM in the area occurred mostly within the low even though, some areas may have a very low values also some crops may adopt to little OM. Most soil fertility experts believe that higher amounts of soil organic matter are related to increased productivity because of its contribution to water holding capacity, improved soil structure, and supply of nutrients [50,46] reported that the Organic Matter (OM) of soils can be classified into different categories, low for soil with organic matter less than 1.5%, medium for soil with OM between 3.1%-4.5%, high for soils with OM greater than 4.5%. The very high category is used for peats and mucks with OM greater than 19% (Fig. 12).

5. GEOSPATIAL METHODS

The spatial associations of the soil parameters were analysed in layers using the Geostatistical methods (IDW). This was done in order to show the spatial variation and concentration of the parameters in the area. The variation of soil properties should be monitored and quantified to understand the effects of land use and management systems on soils [51].

The concentration of pH and P in the area (Figs. 3 and 4) shows a patches of concentration of higher values at the North central and Southern part of the area which has been attributed to the type of agricultural practices in the area. Soil tillage systems lead to increase of soil pH, base saturation, and extractable P [52]. Ca and CEC distribution (Figs. 5 and 6) showing patches of concentration at the Easter and Central part of the area with very low values. The variation for EC in the area (Fig. 7) shows the concentration of higher values at the West and Central part of the area. This is attributed to water logging that causes the soil to be more toxic to some crops.

The distribution of K in the area shows a greater concentration of higher values at the East and Western part of the area (Fig. 8). Distribution of N shows a higher concentration at the central part of the area and a moderate distribution of Mg in the area unless to the East and West central part with very low value (Fig. 10).

OM and OC have similar variation with the highest concentration at the Eastern part of the area (Figs. 11 and 12). The distribution of Na in the area shows a partial concentration of the element unless at the central areas with very low values.

Table 1. Summary table of the analytical data

	N	Minimum	Maximum	Mean	Std. deviation
	Statistic	**Statistic**	**Statistic**	**Statistic**	**Statistic**
Sand	51	56.00	79.00	72.2745	6.24845
Silt	51	7.00	22.00	12.7059	3.85898
Clay	51	11.00	26.00	14.8627	3.27426
Ca (ppm)	51	1.02	9.21	3.2733	2.27058
Mg (ppm)	51	.04	1.23	.6616	.33575
K (cmol/kg)	51	.01	1.01	.2043	.24929
Na (ppm)	51	.01	.23	.0916	.06432
EC (ds/m)	51	.02	51.40	7.9284	8.72084
pH	51	2.90	9.96	6.0318	1.50081
OC (%)	51	.01	.55	.2229	.13027
OM (%)	51	.02	.94	.3812	.22275
N (%)	51	.02	.96	.3057	.31708
P (ppm)	51	0.00	7.80	3.2314	1.99845

Sources: Data analysis (2014)

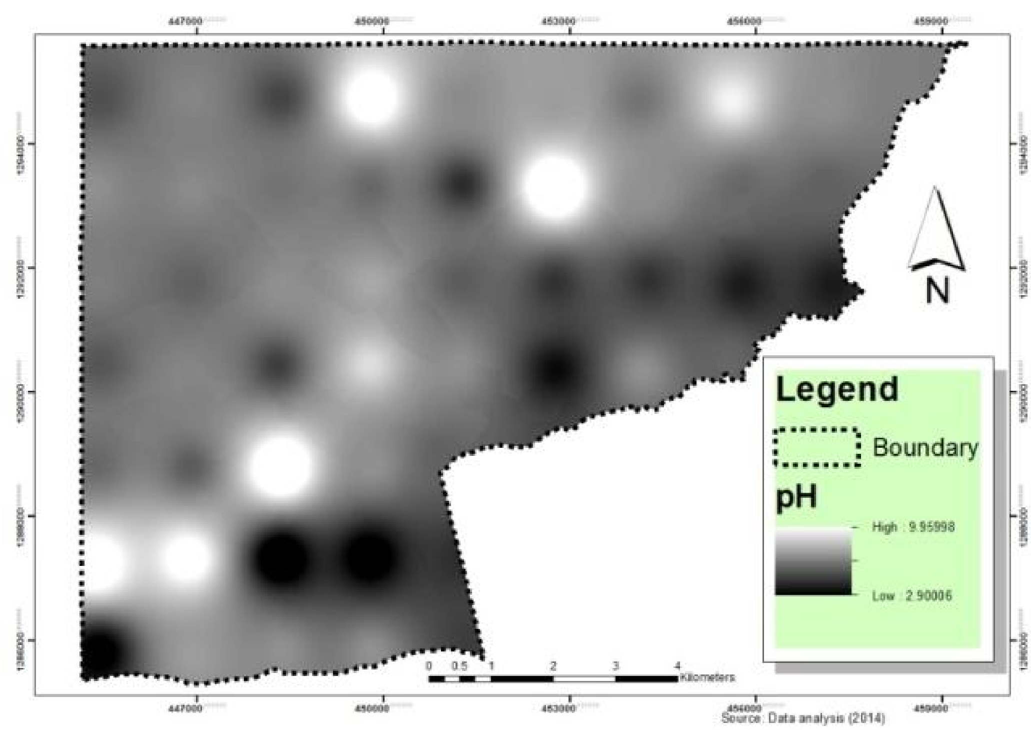

Fig. 3. Spatial distribution of pH

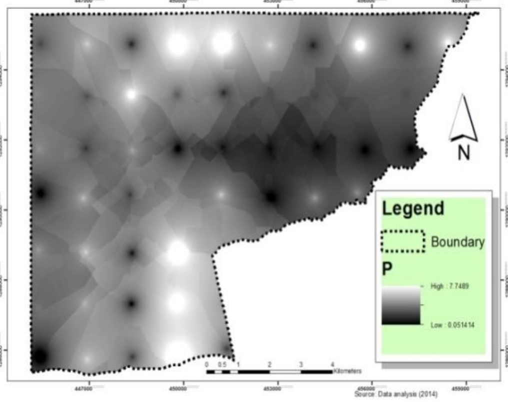

Fig. 4. Spatial distribution of P

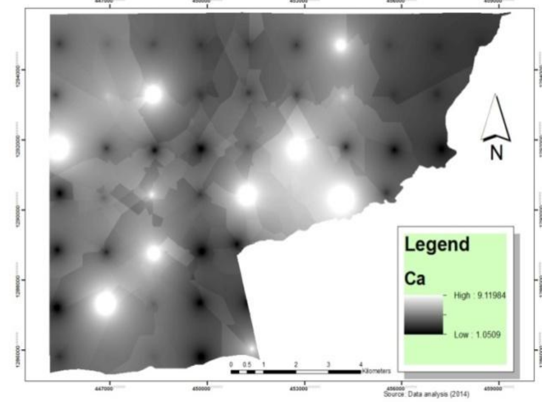

Fig. 5. Spatial distribution of Ca

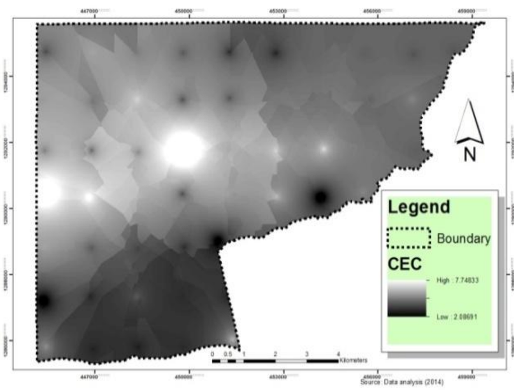

Fig. 6. Spatial distribution of CEC

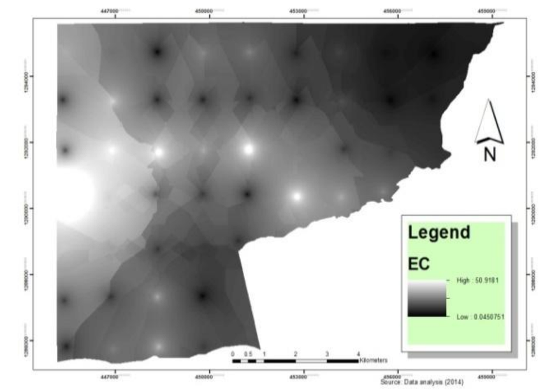

Fig. 7. Spatial distribution of EC

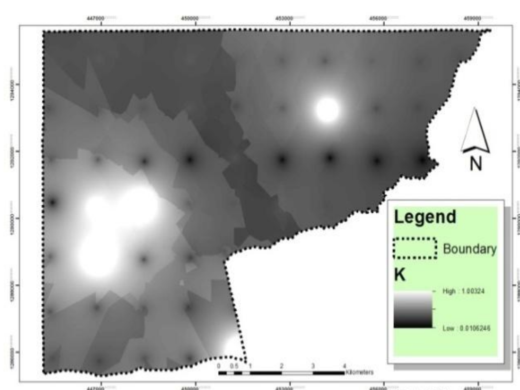

Fig. 8. Spatial distribution of K

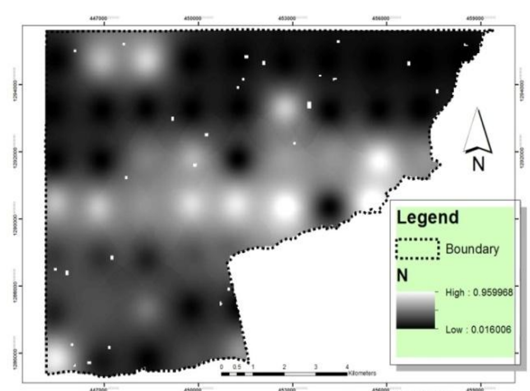

Fig. 9. Spatial distribution of N

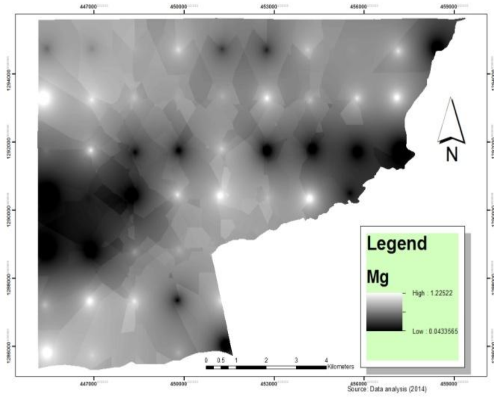

Fig. 10. Spatial distribution of Mg

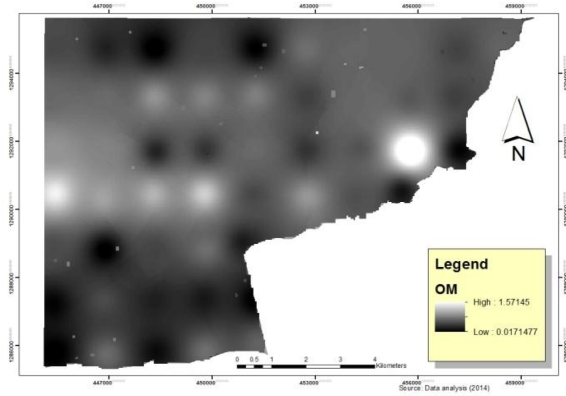

Fig. 11. Spatial distribution of OM

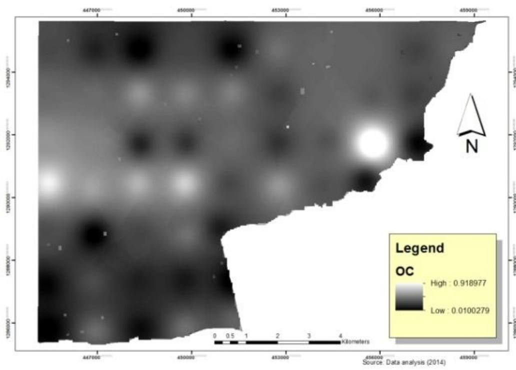

Fig. 12. Spatial distribution of OC

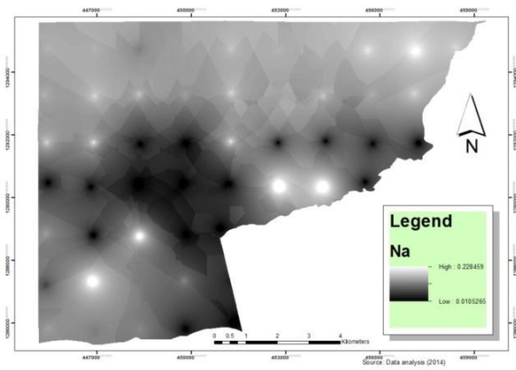

Fig. 13. Spatial distribution Na

6. CONCLUSION AND RECOMMENDATIONS

The study provided a way forward towards achieving the optimum profit in analyzing and mapping of soil information. The study shows that the use of GIS approach simplified the time taking, labour and manpower in conducting the data collection and analysis compared with the conventional approach were soil units and mean values of the parameters were used. The approach would help in finding out an element that is concentrated or deficient which may need attention for management.

The study therefore, concludes that the soil of the area is affected with salinity and some of the essential element that was needed in the soils is deficient. The low pH in some parts of the study area may experience accumulation of micronutrients thereby making the soil to become toxic to some plant and also there is likely to have few microorganisms in the soil.

The concentration N and K in the soil of the area is generally moderate. The available phosphorus across the survey area was low. The soils have moderate CEC, and exchangeable Ca, Mg and K but generally low OC. Soil with low in CEC is known to degrade easily under intensive cultivation. Fortunately the soil has moderate CEC. However, the productivity of soils is expected to decline under intensive cultivation. For instance the decline in organic matter will lead to decline in soil properties such as CEC, water and nutrient holding capacities and soil structural development. However the high exchangeable bases especially Ca, Mg, and K will lead to increase high fertility of the soils.

Intensive cultivation leads to deterioration, compaction, and surface crust of soils. It may also cause structural deterioration results in soil compaction, surface crust, disaggregation and restricted root development. The study recommend for improving the soil fertility. This is correlated to the improvement of soil structure and organic matter as well as the application of fertilizers. The addition of organic matter through of crop residues, recycling of nutrients through ruminant animals and checking of top soil loss from soil erosion through avoids burning of fields should be adopted. Adding inorganic fertilization can be a regular part of land management, and applications may have to be moderate.

It should be noted that during fertilizer application, care has to be taken in considering the result of the GIS analysis (maps) that shows the concentration of the soil parameters, which would serve as a guide during fertilizer application in other to avoid over application that may cause soil pollution and degradation. More studies should be carried out for micronutrient (trace elements like Zn and Fe) in the area using conventional and GIS approach so as to correlate with this study. Also other models for interpolations like Krigging or Spline combined with semivariogram in the spatial analyst may be tested in order to validate the analysis.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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