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Full Length Research Paper

Effects of land use on soil nutrient concentration and fertility using Geospatial technology

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The effects of land use on soil nutrient concentration and fertility were investigated in a research conducted in Akure (Latitude 7^{0}18'12"N and Longitude 5^{0}8'4"E) in 2013 using the GIS interpolation technique. The land use types identified on the GeoEye-1 satellite image were maize, cassava, oil palm and forested areas consisting of bush regrowth and uncleared forest. The feature extraction technique in Arc GIS was used to group and delineate the land use types while soil samples at seven locations were taken from each land use and analysed for nitrogen, phosphorus, potassium, calcium, magnesium and organic matter. The spatial nutrient concentration across the land use types was generated using the GIS kriging technique of 3D Analyst/Raster Interpolation/Kriging Tools while the fertility map was generated using the overlay operations of 3D/Raster Math Tools in ArcMap. The fertility map generated indicated high fertility status in the uncleared forest and oil palm while the greater portion of bush regrowth was of medium fertility and the portion of each of maize and cassava was of low soil fertility.

Key words: Land use, nutrient concentration, soil fertility map, GeoEye-1 Imagery, kriging technique.

INTRODUCTION

The effects of agricultural land use on soil properties, nutrient absorption rate and nutrient use economic efficiency ratio had been documented in previous research (Ndukwu et al., 2010; Chen et al., 2011; Hauser et al., 2012). The extent to which land use types could influence soil nutrients and productivity was reported in an investigation conducted in Ogun State, Nigeria in which land use types of arable cropping, oil palm and secondary forest were investigated and the result showed that soil nutrients varied from one land use type to another and soil depletion and degradation were very prominent under arable cropping than the oil palm and secondary forest (Senjobi and Ogunkunle, 2011). The effects of agricultural land use on soil physical properties was reported in the investigation conducted in the Taleghan watershed of Tehran Province, Iran, and the investigation revealed significant increase in bulk density of 1.39 g cm^{-3}at a depth of 0–30 cm in dryland farm soils compared to pastureland of 1.20 g cm^{-3} (Haghighi et al., 2010). In the research that investigated the conversion of alder coppice forest to tea plantations in the humid Northern Blacksea Region in Turkey, bulk density (Db) increased from 0.84 g cm-3 to 1.02 g cm-3, soil penetrometer resistance (SPR) increased from 0.94 to 1.27 MPa, saturated hydraulic conductivity (Ksat) decreased from 40.64 to 16.33 mm h-1 at 0 to 10 cm depth of soil **(**Yüksek, 2009).

The manual analogue method of land use mapping consisted of a combination of field photos and field notes, hand-mapped trees, shrubs and massifs (Bronsveld and Conway, 2004). The analogue methods of field surveys, cadastral, topographic and thematic mapping were not highly effective to acquire land use because they were time and cost intensive. The application of Geospatial Technologies (GT) had however enhanced greater efficiency in land use mapping which offered a practical and economical means to study vegetation cover changes, especially over large areas and also provided repeated and consistent assessment and monitoring of land use (Langley *et al*. 2001; Nordberg and Evertson, 2003). Geospatial technologies had been described as systems that acquired and handled location-specific data

The flow chart for the methodology adopted in sequence is shown in Figure 1.

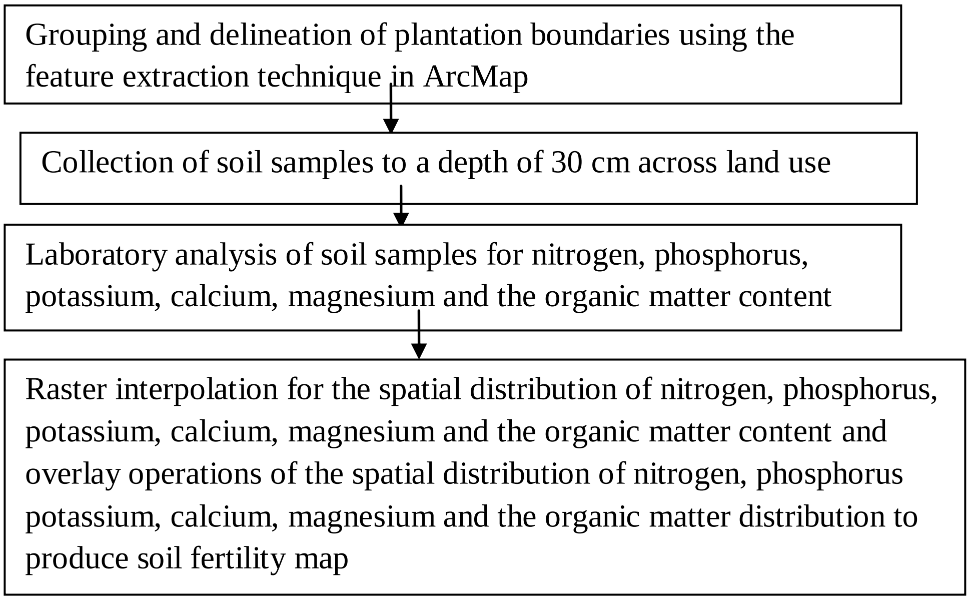

Figure 1. The Flow Chart of the sequence of fertility map production

about earth and comprised a range of modern tools, such as remote sensing, Geographic Information Systems (GIS), and Global Positioning Systems (GPS) that allowed for mapping and analysis of multiple layers of georeferenced data. The application of GT in land use changes was also demonstrated in the evaluation of geographical distribution of different land uses in the savannas (*lavrado*) of Roraima, Brazilian Amazonia in which data were obtained from visual interpretation of very high Ikonos and QuickBird images that resulted in the generation of polygons representing land use categories. The use of GT such as satellite Remote Sensing (RS), GIS and GPS were used effectively to identify suitable sites for various horticultural crops and also for appropriate monitoring and management of land resources in an integrated manner with reference to agro-climatic condition in East Khasi Hills District of Meghalaya, India (Goswami et al., 2012).

The use of GT in the study of the effects of agricultural land use on soil properties and the yield of crops had been reported in previous research (Adekayode et al., 2009; Aboelghar et al., 2011; Adekayode and Akomolafe, 2011; Bocco et al., 2012; Sarmah et al., 2011). The use of GT to study the effects of agricultural land use on soil chemical properties was reported in the studies in Shunyi District's cropland with the use of remote sensing and ground census data based on the Geostatistical Analyst of ArcGIS. The study revealed the southwestern and northeastern areas of the district to be high in soil pH, while the wide variability of organic matter, total N, available P and K could be due to the extent of land use (Zhao et al., 2011). The variation features of soil fertility under different land use types and soil management practices using Grey Relational Analysis (GRA) and GIS were investigated in research conducted in Beijing, China and the result showed that the main factors influencing the spatial distribution of soil fertility quality were land use and soil management practices with the increasing trend of soil fertility quality attributed to the widespread practices of organic manure applications (Jin et al., 2011). The application of GT was employed in the spatial analysis of soil fertility management systems in small holder Kenya farms where determinants of soil fertility management practices, including both the use of cattle manure and inorganic fertilizer data were obtained from a sample of 3,330 geo-referenced farm households across Central and Western Kenya (Staal et al., 2003).

The objective of the study was to use geospatial technology to investigate the effects of land use on the spatial nutrient concentration and the fertility status of a farmland in Akure ($7^0$18'12"N, $5^0$8'4"E), Nigeria.

MATERIALS AND METHODS

Feature extraction of land use on GeoEye-1 satellite image

The agricultural land use features identified on the image were arable crops comprising of maize and cassava, tree

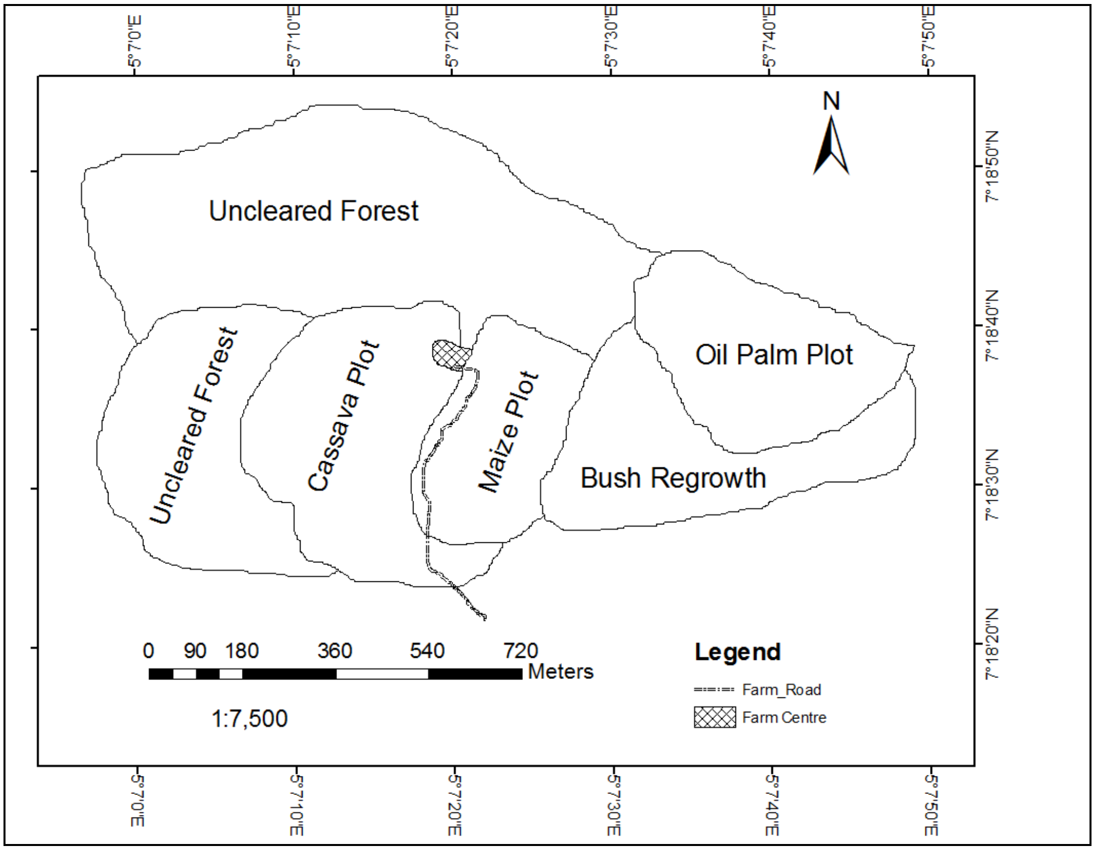

Figure 2. Land use lay out of maize, cassava, oil palm and the forested areas of bush regrowt and uncleared forest

crop comprising of oil palm, forested areas consisting of bush regrowth and uncleared forest. The land use types were created as polygon features in the projected coordinate systems of WGS 1984 UTM Zone 31N in ArcCatalog and each digitized as a layer in ArcMap (Puig et al., 2002; Zanella et al., 2012).

Soil sampling and laboratory analysis

Soil samples to a depth of 30 cm from seven locations in each land use were taken for laboratory analysis. Soil samples were air-dried and sieved through a 2 mm sieve and analysed for nitrogen, phosphorus, potassium, calcium, magnesium and organic matter content following the laboratory procedures described by Carter (1993). Organic carbon was determined by oxidising soil sample with dichromate solution and later titrated with ferrous sulphate solution. The total nitrogen was determined using micro-kjeldahl method and the available phosphorus determined by the Bray P-1 method. The exchangeable cations were extracted by leaching 5 g of soil with 50 ml ammonium acetate at pH 7 and the potassium in the leachate determined with a flame spectrophotometer while the calcium and magnesium were determined on the atomic absorption spectrophotometer.

Interpolation technique for spatial distribution of nitrogen, phosphors, potassium, calcium, magnesium and the organic matter content and overlay operations for the production of soil fertility map

The spatial distribution of nitrogen, phosphors, potassium, calcium, magnesium and the organic matter content was carried out separately for each element with the 3D Analyst/Raster Interpolation/Kriging Tools while the overlay operations to generate the soil fertility map was carried out using the 3D Analyst/Raster Math/Plus Tools in ArcMap.

RESULT

Figure 2 shows the land use indicating the lay out of plantation of maize, cassava, oil palm and the forested

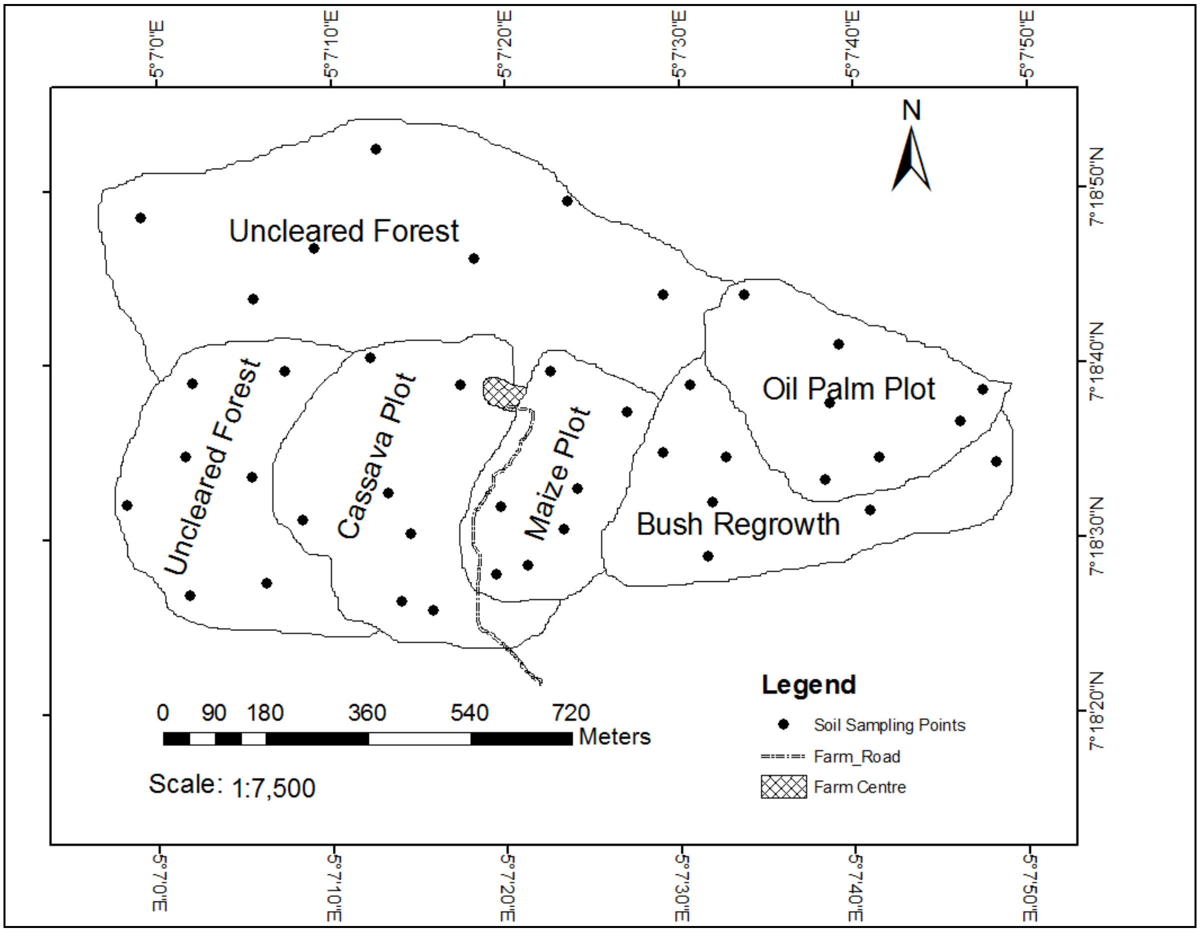

Figure 3. Land use layout with soil sampling locations.

areas of bush regrowth and uncleared forest covering areas of 9.9 ha, 17 ha, 13 ha, 13.5ha and 49.2 ha respectively.

The locations for soil sampling are shown in Figure 3. The land use which had been grouped into five areas of maize, cassava, oil palm, bush regrowth and uncleared forest had seven soil sampling locations in each land use type to make a total of thirty five soil sampling locations with their coordinate readings in the Universal Transverse Mercator (UTM) projection (Table 1). The soil sampling points were identified on the ground with the use of GPS receiver.

Figure 4 shows the fertility status of soils across the land use of maize, cassava, oil palm, bush regrowth and uncleared forest.

The cropping of land under maize and cassava resulted into low soil fertility while the greater portion of bush regrowth was of medium fertility whereas the greater portion of oil palm and the uncleared forest had high fertility.

DISCUSSION

The GeoEye-1 satellite image at a resolution of 0.5 m which was already geometrically corrected and ortho-rectified showed clearly land use of maize, cassava, oil palm, bush regrowth and uncleared forest and the features identified and delineated into polygons using visual interpretation and feature extraction techniques respectively in ArcGIS (Figure 2). The procedures adopted was a manual digitization of features and the conversion to a vector layer in ArcMap which corroborated previous method reported in Topan et al. (2009) in the feature extraction of features in the mountainous urban area of Zonguldak city centre in Turkey, whereby such parameters as the geometric-, radiometric- and spectral resolution, object contrast, atmospheric conditions, sun elevation and topographic conditions were used for object identification. The procedures of interpretation also agreed with the principle previously adopted in Backes and Jacobi (2006) to detect

Table 1. Soil chemical properties across the land use.

Soil sampling location Easting	Northing	Land use (Crop)	N (%)	P (ppm)	K	Ca cmol/kg	Mg	OM (%)
734369	808680	Maize	0.18	12.2	0.21	2	1.86	0.21
734504	808609	Maize	0.16	11.2	0.22	2.18	1.65	0.38
734417	808474	Maize	0.20	10.9	0.24	2.16	1.86	0.36
734282	808442	Maize	0.14	11.6	0.23	2.25	1.48	0.34
734393	808402	Maize	0.18	12.1	0.26	2.48	1.38	0.31
734329	808339	Maize	0.19	10.9	0.17	3.12	1.97	0.37
734274	808323	Maize	0.16	12.8	0.18	2.76	1.86	0.38
734051	808704	Cassava	0.18	11.2	0.23	2.12	1.76	0.32
733932	808418	Cassava	0.14	12.2	0.21	1.98	2.21	0.34
734163	808260	Cassava	0.13	10.8	0.24	2.45	2.21	0.28
734210	808656	Cassava	0.14	11.6	0.22	2.43	1.65	0.26
734083	808466	Cassava	0.13	12.2	0.21	2.18	1.87	0.32
734123	808394	Cassava	0.16	11.8	0.26	2.54	2.15	0.31
734107	808275	Cassava	0.18	10.8	0.24	2.48	2.11	0.29
734710	808815	Oil Palm	0.24	12.7	0.28	2.34	2.43	1.23
735091	808593	Oil Palm	0.26	13.4	0.31	2.12	0.88	1.26
734853	808490	Oil Palm	0.21	12.8	0.24	3.24	1.23	1.18
734861	808625	Oil Palm	0.32	14.1	0.26	2.45	1.65	1.25
734948	808529	Oil Palm	0.28	13.2	0.34	2.46	0.97	1.19
735131	808648	Oil Palm	0.26	13.6	0.32	3.12	1.24	1.26
734877	808728	Oil Palm	0.27	12.9	0.27	3.42	0.98	1.24
734567	808537	Bush regrowth	0.28	13.6	0.24	2.12	1.86	1.38
734933	808437	Bush regrowth	0.26	14.2	0.26	2.43	2.12	1.36
734615	808656	Bush regrowth	0.24	13.9	0.23	2.18	2.5	1.36
734679	808529	Bush regrowth	0.28	13.6	0.21	2.43	2.54	1.32
734647	808355	Bush regrowth	0.22	13.2	0.25	2.18	1.98	1.28
735155	808521	Bush regrowth	0.24	14.6	0.26	2.64	2.14	1.34
734655	808450	Bush regrowth	0.26	14.2	0.22	2.48	2.24	1.31
733869	808307	Uncleard Forest	0.27	12.8	0.25	2.64	2.14	1.32
733726	808529	Uncleard Forest	0.28	12.6	0.28	2.48	2.26	1.31
733901	808680	Uncleard Forest	0.28	13.2	0.24	2.43	3.13	1.28
733647	808950	Uncleard Forest	0.27	12.9	0.22	2.46	3.25	1.22
733845	808807	Uncleard Forest	0.28	13.8	0.28	2.68	3.64	1.21
734234	808879	Uncleard Forest	0.26	14.2	0.25	2.18	3.87	1.37
734567	808815	Uncleard Forest	0.3	13.6	0.32	2.68	2.87	1.38

Table 1. Cont.

733952	808897	Uncleard Forest	0.27	12.8	0.35	2.46	2.97	1.32
734400	808981	Uncleard Forest	0.25	13.9	0.26	2.19	2.43	1.36
733738	808658	Uncleard Forest	0.29	14.1	0.22	2.67	2.98	1.37
733624	808444	Uncleard Forest	0.28	14.6	0.25	2.76	3.45	1.32
733734	808285	Uncleard Forest	0.32	13.9	0.24	2.58	2.86	1.38
733843	808494	Uncleard Forest	0.27	13.5	0.26	2.76	2.76	1.34
734062	809071	Uncleard Forest	0.28	14.8	0.27	2.18	3.02	1.32

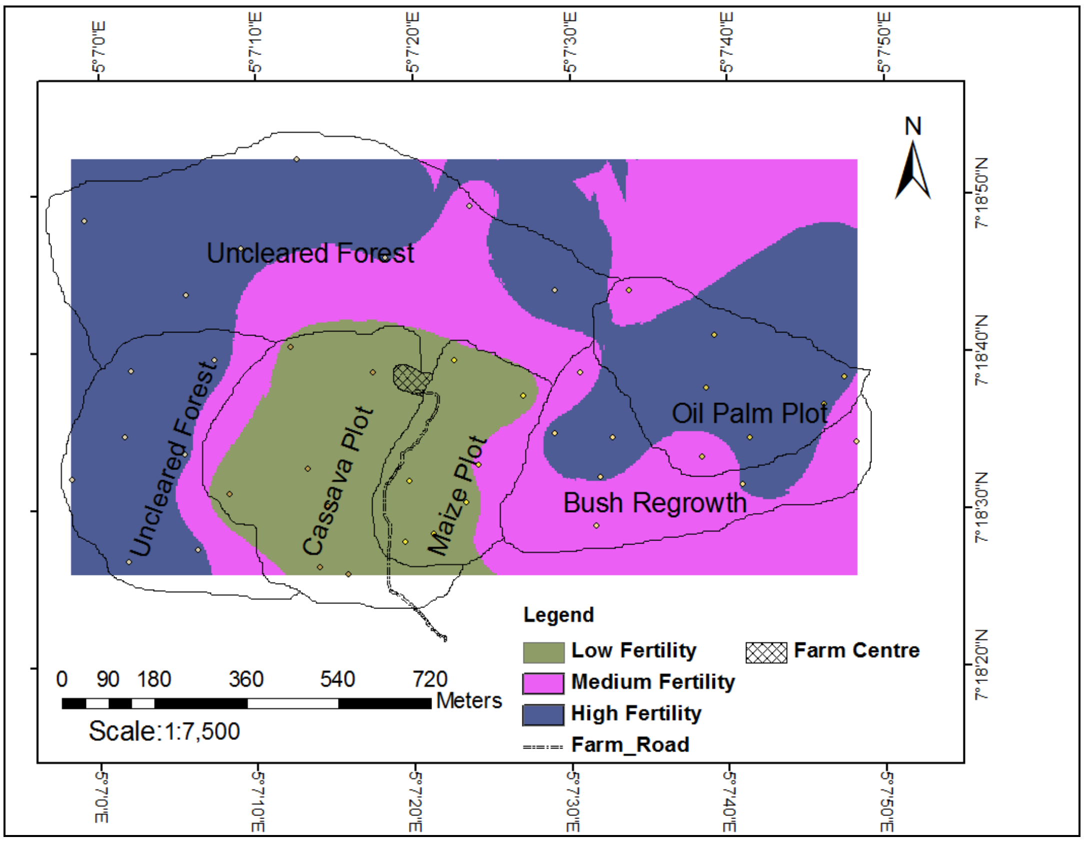

Figure 4. Fertility status of soils across the land use types.

and delineate weed infested portion in a field of sugar beets (*Beta vulgaris* L.) in Bonn, Germany. The areas of 9.9 ha, 17 ha, 13 ha, 13.5ha and 49.2 ha under maize, cassava, oil palm and the forested areas of bush regrowth and uncleared forest respectively was generated from the attribute table link to the spatial data. This was accomplished by creating a theme to control the appearance of features in the spatial data following the procedures in Andrienko and Andrienko (2001).

The soil sampling points located in Figure 3 were identified on the ground with the use of Global Positioning System (GPS) receiver in a method similar to that previously adopted by Rosenberg and Anderson (2011) in which the method showed a combined application of GPS and GIS to collect and analyze data for site-specific farming. The applications were used for farm planning, field mapping, soil sampling, tractor guidance, crop scouting, variable rate applications and yield mapping. The use of GPS and GIS tools in soil sampling locations and the digital generation of soil map in Figures 2 and 3 respectively, corroborated the previous work by Adekayode et al. (2009) on the sampling of soils based on soil-slope relationship in a precision soil fertility investigation in Akure, Nigeria. Earlier research in the use of GPS and GIS technology in soil studies was reported by Lachapelle et al. (1996).

The values of soil nutrients in Table 1 were used to generate a spatial distribution of each nutrient and the fertility map in Figure 4. The spatial distribution of each nutrient concentration of nitrogen, phosphorus, potassium, calcium, magnesium and organic matter content into low, medium, and high was generated with the use of interpolation toolset of 3D Analyst/Raster Interpolation/Kriging Tools, by which predicted values were assigned to all other locations to create continuous surface representation of the nutrient concentration. The kriging interpolation method used was a geostatistical method based on a statistical model of autocorrelation meant to provide some measure of the accuracy of the prediction (Royle et al., 1981; Oliver, 1990). The spatial representation of nutrient concentration also followed the procedures of the kriging method employed by Adekayode et al. (2013) while the soil fertility map categorized into low, medium and good fertility classes was generated by overlay operations with the use of the 3D Analyst/Raster Math/Plus Tools in ArcMap following the previous procedures in Liu et al. (2002). The principle in the overlay analysis performed was premised on the use of weighted overlay tool by which a common scale of values was applied to the concentration of the different elements to produce an integrated soil fertility classes. The basic principle of the overlay operation was the intersection of the input polygon boundaries to produce new polygons with all the attributes of the original polygons. The procedure corroborated the previous findings of Ebitsu and Minale (2013) in the preparation of suitability map by overlay analysis on Arc map to classify solid waste dumping in Bahir Dar Town, Ethiopia as unsuitable, moderately suitable and most suitable. The same principle was used to generate suitability map of Tana delta in Kenya with regard to areas suitable for rice growing. The areas were categorized into four classes of most suitable, suitable, less suitable and unsuitable based on selected theme layers of landform, soil texture, soil sodicity and salinization (Kuria et al., 2011).

CONCLUSION

The geospatial technology was used to generate the digital map that showed the land use layout of maize, cassava, oil palm and the forested areas of bush regrowth and uncleared forest with the corresponding areas of 9.9 ha, 17 ha, 13 ha, 13.5ha and 49.2 ha respectively. The kriging interpolation technique and the overlay operations were used to prepare the soil fertility map which classified land under maize and cassava into low soil fertility while the greater portion of bush regrowth was of medium fertility whereas the greater portion of oil palm and the uncleared forest were of high fertility.

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