ASN 53rd Annual Conference Proceedings (Sub-Theme: Soil Conservation, Fertility and Water Mgt.)

Geographic Information System (GIS)-Based Digital Mapping of Soil Properties for Arable Agriculture in Ike-Bunu, Kogi State

E. O. Robert, B. A. Lawal, and J. A. Odofin
Department of Soil Science and Land Management, Federal University of Technology, Minna, Niger State
E-mail: roberte53@gmail.com, Phone No.: 08067654222

Abstract
Geographic information system (GIS) technology is increasingly applied in mapping of soil properties and land attributes, as it hastened decision making processes. This study assessed and mapped the potentials of a 21,692.51 ha parcel of land in Ike-Bunu, Kogi State, using soil/land attributes and evaluated their potential for arable agriculture. Six mapping units were delineated, namely: MU-1 (3391.35 ha), MU-2 (1689.65 ha), MU-3 (1549.66 ha), MU-4 (5065.96 ha), MU-5 (4905.390 ha) and MU-6 (hilly terrain, 6,977.03 ha) based on soil properties and terrain analysis. Five (5) profile pits were dug across the study site and described according to FAO guidelines. Soil samples were collected from each identified genetic horizons for laboratory analysis. GIS database was generated for selected soil physical and chemical properties using ArcGIS 10.3 application. Results showed the dominant textural class of the soils was sandy loam underlain by sandy clay loam. Values of bulk density (BD) ranged from 1.04 to 2.35g cm^3. Soil pH rated from strongly acidic to neutral (pH 4.8 to 6.9). Organic carbon (OC) was low (2.14 to 8.57 g kg^{-1}), total nitrogen (N) was high (0.84 to 2.66 g kg^{-1}), available P was low (1.0 to 8.0 mg kg^{-1}) and potassium content was low to high (0.02 to 1.68 cmol kg^{-1}). All the soil mapping units except the hilly terrain have potentials for arable agriculture. Hilly terrain could be used for agroforestry.
Keywords: Digital soil map, Agricultural potential, physical and chemical properties.

Introduction

Specific geographical features that have been identified in scientific investigations such as topography, river, soil and vegetation (Senhor, 2018), could also be reported in the form of a geographic information system (GIS). Soil and vegetation have strong mutual relationship. Soil provides nutrients, moisture, and anchorage to vegetation to grow effectively, while in turn vegetation provides protective cover for soil, reduces soil erosion, and helps to protect soil nutrients through litter accumulation and subsequent decay (Eni *et al.,* 2011). Soil, nevertheless is fundamental to ecosystem and agricultural sustainability and production because it supplies many of the main requirements for plant growth like water, nutrients, anchorage, oxygen for roots, and moderated temperature (Jamieson *et al.,* 2002, Van der Maarel 2004, Eni *et al.,* 2011). According to Marlborough District Council (2016), soils act as buffers to capture and store nutrients and microbes, treat a range of waste products, and store and filter water. Digital data acquired from sensors platforms such as Landsat, Google Earth have been used to increase landscape survey reliability (Steven, 1986). Before the introduction of Digital Elevation Models (DEMs), landforms were identified by means of interpretation of aerial photographs (Calogero *et al.,* 2015). Terrain information extracted from Digital Elevation Models (DEM) may be related to the specific morphometry of landforms or the general geo-morphometric characteristics of land surfaces (Steven, 1986). Web Soil Survey (WSS, 2017) provides soil data and information produced by the National Cooperative Soil Survey. The website was activated by the USDA Natural Resources Conservation Service (NRCS) and provides access to the largest natural resource information system in the world. Natural Resources Conservation Service (NRCS) has soil maps and data available online for more than 95 percent of the nation's counties in the USA and expected to have 100 percent in the near future.

Materials and Methods

The Study Site: The study site was an undeveloped forest land (21,692.51 ha) near Ike-Bunu in Kabba Bunu Local Government Area, Kogi State, Nigeria. The site lies between latitudes 8° 26' 1.642" N and 8° 14' 40.897" N, and longitudes 6° 29' 56.788" E and 6° 17' 56.78" E, on elevation ranging from 75 to 314 m above sea level. It lies within southern Guinea savanna vegetation zone. The annual rainfall is about 1338 mm which falls between May and November (Okoye *et al.,* 1995). The geology is basement complex rocks made up of migmatite-gneiss and granite-gneisses (KSMSMD, 2004; Ojanuga, 2006; Fatoye, 2018).

Siting of profile pits and ground thruthing: Satellite imagery (Space Shuttle Radar Topography Mission (SRTM)) of the site was used to extract digital geo-referenced data to plot the boundaries of the site and prepared the contour map used as base-line for the field work following the guidelines of Andrea *et al.* (2005). The vectorised imagery and the topography map aided the provision of land information system (LIS) used as a guide in siting five representative profile pits in the entire study site. Coordinates of each identified point was extracted using AutoCAD and ArcGIS 10.3 Application and data inputted into Hand-held Global Positioning System (GPS) device for purpose of ground thruthing and subsequent creation of database for each profile pit. Properties attributed to profile such as soil depth, texture, bulk density, pH, organic carbon, total nitrogen, available phosphorus, potassium formed part of the database using ArcGIS analysis.

Digital map of the site was produced using the geo-referenced laboratory data of the selected soil properties. Point Krigging was used in modelling and extrapolation of data obtained from visited spoints (profiles) to other areas not visited to produce digital map. The geostatistical interpolation followed the equation:

$$Z*(x_0) = \sum_{i=1}^{n} \lambda i Z(xi) \quad \text{............ (1)}$$

where $Z*(x_0)$ is the value to be predicted at the location x_0, $Z(x_i)$ is the known value at the sampling location xi, n is the number of locations within the search neighborhood used for the prediction, and λi is the kriging weight assigned to $Z(x_i)$ (Bhunia *et al*., 2016; Pravat *et al.,* 2016).

Profile description and sampling: Ten profile pits were dug to specification (2m x 1m x 1m) and described in the field according to FAO guidelines (FAO, 2006). One typical profile pit representative for each mapping unit was sampled for laboratory analysis. Soil sampling was collected sequentially from genetic horizons starting from bottom to top of the profiles.

Laboratory Analysis: The soil samples were air-dried, gently crushed in a mortal and sieved with 2 mm mesh and analysed for selected soil properties. Bulk density was also determined using clod method (ISO, 2017). Particle size distribution was by Bouyoucos hydrometer method (Bouyoucos, 1962). Soil pH (1:2.5) in water was determined using a glass electrode pH meter. Organic carbon content using the chromic acid oxidation procedure of Walkley and Black (Walkley and Black, 1934). Total Nitrogen was analysed by the micro-kjeldahl digestion method (Bremmer, 1996), followed by distillation and titration. Available phosphorus was extracted using Bray P1 method (Bray and Kurtz, 1945). Exchangeable potassium (K) was extracted with neutral 1N NH_4OAC solution. Potassium in the extract was determined using flame photometry (Thomas, 1982).

Results and Discussion

On the basis of the results of selected soil properties, six mapping units was digitally produced (Figure 1). The units were designated as MU-1 (3391.35 ha), MU-2 (1689.65 ha), MU-3 (1549.66 ha), MU-4 (5065.96 ha), MU-5 (4905.390 ha) and MU-6 (hilly terrain, 6,977.03 ha) based on soil properties and terrain analysis. Information regarding to soil properties are discussed below.

Physical properties: The results of selected physical properties are presented in Table 1. All mapping units have sandy loam texture underlain in some pedons by sandy clay loam. This could be attributed similar parent materials and environment in which the soils were developed. Bulk density of the topmost three horizons corresponding to root-zones ranged from 1.04 g cm^{-3} to 2.35 g cm^{-3}. Bulk density range of 1.00 to 1.70 is favourable for arable crop production (Allison. 2006). These results imply that MU-5 may not favour cultivation of deep rooted crops such as yam and cassava. According (Ahmed *et al.,* 2018; Usowicz *et al.,* 2013) soil bulk density is also a key value to estimate soil moisture content and total porosity.

Chemical properties: The results of selected chemical properties of the soils are presented in Table 2. Soil pH in an important soil properties that determine solubility and reaction of soil elements such as Al and Mn (John *et al*., 2018). The pH of the topmost three horizons ranged from 4.8 to 6.9 which according to Chude *et* *al*. (2011) classification falls under strongly acidic to neutral. Soil pH range of 5.5 to 7.0 have been established as favourable for release of most crop/plant nutrients (Brady and Weil, 2002). On this basis, MU-3 which covers ….ha had surface pH of 5.1 may require liming as part of its management for optimal and sustainable crop production. The soil organic carbon ranged from 2.14 to 8.57g kg^{-1} and was low according to Esu (1991) fertility classification. Reasons for low organic matter might be due to the seasonal bush burning. Organic matter play important role in soil by binding soil mineral particles and provide exchange sites for nutrients. Management of these soils for intensive arable crop should put into consideration practices that will encourage return of crop residues back to soil. Total nitrogen was high (0.84 to 2.66g kg^{-1}) probably due to the land being under forest vegetation for ages. Available phosphorus ranged from 1.0 to 8.0 mg kg^{-1} which was low and potassium (K) ranged from 0.02 to 1.68 cmol kg^{-1} and was rated low to high. Low P in the soil units might be attributed to inherent properties of parent materials that formed the soils. Thus, Seid *et al.* (2017) suggested that to increase any economical agricultural production in such low P soils, will require raising of available P through various management practices such as application of organic manure or phosphorus-rich fertilizers. The soil units MU-1 and MU-2 with low K contents may require external K support through fertilizer application.

Conclusion

The study shows that, GIS-based mapping of soil properties could ease identification and mapping of suitable land for agricultural purposes in Ike-Bunu Kogi State. Important management information for the site could be deduced easily. Regarding to tillage operations, uniform treatment is possible. However, in terms of bulk density, MU-5 may affect choice of deep-rooted crops. Liming of the soils may not be required except in MU-3 with low pH. Potassium fertilization may form part of management of MU-1 and MU-2. In general, the study site has potentials for arable agriculture if these limitations could be amended.

REFERENCES

Ahmed A.G., AL-Shammary A., Kouzan Z., Akif K., Sui Yang K., Michael N., and Will G., (2018) Soil Bulk Density Estimation Methods: A Review, Pedosphere v 28:581–596

Allison A.T. (2006): Effects of bulk density and soil strength on the growth of blue wildrye (elymus glaucus buckl.), The Faculty of Humboldt State University, Rangeland Resources and Wildland Soils.

Andrea, B., Vicente T.R., Valentino S., Dawn F., Mario A.O., (2005): Geo-morphometric analysis for characterizing landform in Moreloss State, Mexico. Geomorphology 67(2005) 407-422.

Bhunia GS, Shit PK, Maiti R (2016) Comparison of GIS-based interpolation methods for spatial distribution of soil organic carbon (SOC). J Saudi Soc Agric Sci. doi:10.1016/j.jssas.2016. 02.001.

Bouyoucos, G. J. (1962): Hydrometer methods improved for making particle size analysis of soil*. Soil science of African proceeding,* 26, 464 - 465.

Brady, N. C., and Weil R., (2002). The Nature and Properties of Soils. 13th edition. Singapore,

Bray, R.H. and Kurtz, L.T. (1945): Determination of total organic and available forms of phosphorus in soil. *Soil Science*, 599, 39 - 45.

Bremmer, J.M. (1965): Inorganic forms of Nitrogen. In C.A. Black *et al. Methods of Soil Analysis.* (pp. 1179-1237) Monograph 9. Part 2. American Society of Agronomy, Madison, Wisconsin.

Calogero, S, Andreas B and Jan K., (2015): Terrain analysis and landform recognition: Geomorphological Techniques, Chap. 2, Sec. 4.2 (2015): 2047-0371.

Chude, V.O., Olayiwola S.O. Osho, A.O., and Daudu, C.K., (2011). Fertilizer Use .and Management Practices for Crops inNigeria. Fourth edition. Federal Fertilizer Department, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria, 215 pp

Eni, D. D., Iwara A.I., Offiong R. A. (2011): Analysis of Soil-Vegetation Interrelationships in a South-Southern Secondary Forest of Nigeria. International Journal of Forestry Research Volume 2012, Article ID 469326, 8 pages http://dx.doi.org/10.1155/2012/469326

Esu, I. E. 1991. Detailed soil survey of NIHORT Farm at Bunkure, Kano State, Nigeria. Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria. 72 pp.

Fatoye, F.B., (2018): Geology and Mineral Resources of Kogi State, Nigeria. *International journal of multidisciplinary sciences and engineering.* Department of Mineral and Petroleum Resources Engineering, Kogi State Polytechnic, Lokoja, VOL. 9, NO. 7, JULY 2018, Nigeria. ISSN: 2045-7057.

Food and Agricultural Organization (FAO) (2006): Guidelines for soil profile description. Soil Resources, Management and Conservation Service, Land and Water Development Division, FAO, Rome; 2006.

ISO (2017): International Organization of Standardization. ISO 11272-2017. Soil quality- Determination of dry bulk density. International Organization of Standardization. Geneva

Jamieson, T., Gordon R., Cochrane L., and Patterson G., (2002): Fundamental aspects of soil-water-plant relationships. Resource Stewardship Division, NS Department of Agriculture and Fisheries-Truro, Nova Scotia, View at Google Scholar

John J. T., Balthazar M.M., Johnson M. S., Ernest S. and Sibaway B. M. (2018): Pedological Characterization and Classification of Some Typical Soils in Three Agro-Ecological Settings of South-Eastern Tanzania, International Journal of Scientific & Engineering Research Volume 9, ISSN 2229-5518

Kogi State Ministry of Solid Minerals Development, KSMSMD (2004): Guide to Investment Opportunities in the Solid Minerals Sector of Kogi State. 26 p.

Marlborough District Council (2016): Soil Properties in the Wairau Valley. Technical Report No: 16-005,

Ojanuga, A.G. (2006). Agroecological zones of Nigeria. FAO/NSPFS, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria, 124 pp.

Okoye, E.O., Kolajaiye T.O, Ugwu, A.O, Popoola, G.I., Nwaka, C.O, (1995). Reports on Soil Survey of Niger State.Compiled by Amba: E.A Federal Department of Agriculture and Land Resources 51-53pp. Pearson Education. 976pp.

Pravat K.S., Gouri S.B., Ramkrishna M. (2016): Spatial analysis of soil properties using GIS based geostatistics models. Model. Earth Syst. Environ. (2016) 2:107

Seid, M., Kibebew K. and Muktar M. (2017): Characterization and Classification of Soils along Toposequence of Gobeya Sub-Watershed, South Wello Zone, Ethiopia. *Asian Journal of Soil Science and Plant Nutrition*. 2(4): 1-17.

Senhor, A.S., (2018): Geographical features are naturally occurring features and also those the result of human creation, B.S. Geography & Environmental Management, University of Ilorin. Answered Mar 11, 2018

Steven E.F., (1986): Terrain Analysis from Digital Patterns in Geomorphometry and Landsat MSS Spectral Response. Vol. 53, No. 1, January 1987, pp. 59--65.

Thomas, G.W. (1982): Exchangeable cations, In Miller, R, H., Page, A. L., and Keeney, D. R. (Eds). *Methods of soil analysis. Part 2. 2nd edition*. (pp. 159-165) American Society of Agronomy and Soil Science of America. Madison. Wisconsin, USA.

Usowicz B, Lipiec J, Usowicz J.B., Marczewski W. 2013. Effect of aggregate size on soil thermal conductivity: Comparison of measured and model-predicted data. Int J Heat Mass Trans- fer. 57: 536–541.

Van der Maarel E., (2004): Vegetation Ecology, Blackwell, Oxford, UK

Walkley, A. and Black, I.A. (1934): An examination of the degtiareff methods for determining soil organic carbon and proposed modification of chromic acid titration method. *Soil science*, 37, 29 - 38.

WSS (2017).websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

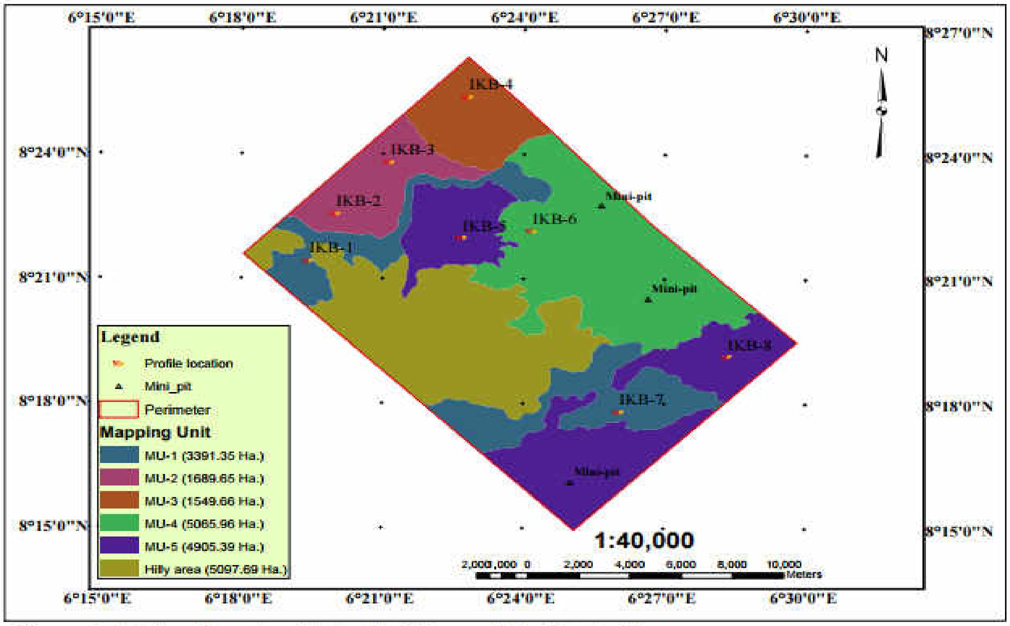

Figure 1.0: Map Showing Major Soil Type of the Study Site

Table 1: Physical properties of the soils of Ike-Bunu

Soil Mapping Unit	Soil Depth	Sand	Silt	Clay	Textural class	BD
	(cm)		(g kg^{-1})			(g cm^{-3})
MU-1	0 – 7	741	65	194	SL	1.04
	7 – 29	691	75	234	SCL	1.11
	29 – 60	761	55	184	SL	1.25
	60 – 69	621	55	324	SCL	1.32
	69 – 92	601	85	314	SCL	1.24
	92 – 174	561	105	334	SCL	1.27
MU-2	0 – 9	771	45	184	SL	1.39
	9 – 24	781	45	174	SL	1.27
	24 – 50	761	55	184	SL	1.12
	50 – 121	631	75	294	SCL	1.12
	121 – 135	611	115	274	SCL	1.81
	135 – 159	571	125	304	SCL	1.20
	159 – 195	591	125	284	SCL	1.14
MU-3	0 – 10	781	45	174	SL	1.18
	10 – 33	741	65	194	SL	1.42
	33 – 67	731	55	214	SCL	1.17
	67 – 190	661	35	304	SCL	1.95
MU-4	0 – 9	791	45	164	SL	1.50
	9 – 24	771	65	164	SL	1.04
	24 – 37	741	85	174	SL	1.08
	37 – 60	761	55	184	SL	1.03
	60 – 111	631	95	274	SCL	1.04

	111 – 147	-	-	-	-	-
MU-5	0 – 6	711	105	184	SL	1.17
	6 – 10	671	95	234	SCL	1.10
	10 – 22	601	105	294	SCL	2.35
	22 – 61	631	65	304	SCL	2.15
	61 – 72	-	-	-	-	-
	72 – 82	581	105	314	SCL	1.10

Note: SL = sandy loam, SCL = sandy clay loam, BD=Bulk density

Table 2: Chemical properties of the soils of Ike-Bunu

Soil Mapping Unit	Soil Depth (cm)	pH (H_2O)	OC (g kg^{-1})	N	P (mg kg^{-1})	K (cmol kg^{-1})
MU-1	0 – 7	6.3	6.86	2.66	2	0.02
	7 – 29	5.6	6.43	1.68	1	0.09
	29 – 60	5.4	5.79	1.40	2	0.07
	60 – 69	5.4	4.71	1.96	1	0.04
	69 – 92	5.5	5.36	1.40	1	0.02
	92 – 174	6.2	4.29	1.82	1	0.11
MU-2	0 – 9	5.8	4.93	1.54	3	0.07
	9 – 24	5.6	5.14	1.12	2	0.07
	24 – 50	5.2	4.50	1.96	2	0.07
	50 – 121	5.5	3.86	2.10	1	0.12
	121 – 135	5.6	3.43	0.98	1	0.14
	135 – 159	6.1	2.57	1.26	1	0.07
	159 – 195	6.2	3.21	1.68	3	0.05
MU-3	0 – 10	5.1	5.57	1.40	6	0.20
	10 – 33	6.4	8.57	1.96	3	0.32
	33 – 67	6.3	4.71	2.24	3	0.22
	67 – 190	5.2	4.93	1.26	3	0.22
MU-4	0 – 9	6.2	3.64	1.68	3	0.42
	9 – 24	6.0	8.57	1.12	2	0.13
	24 – 37	5.7	4.93	1.40	2	0.70
	37 – 60	5.3	5.36	0.84	1	0.10
	60 – 111	5.0	4.29	1.54	1	0.08
	111 – 147	-	-	-	-	-
MU-5	0 – 6	5.6	5.14	1.40	3	0.33
	6 – 10	5.4	5.36	1.12	3	0.88
	10 – 22	5.4	8.14	0.84	3	0.56
	22 – 61	5.5	8.79	1.96	2	0.56
	61 – 72	-	-	-	-	-
	72 – 82	6.2	7.50	1.26	1	2.08

Note: OC = organic carbon, N = total nitrogen, CEC = cation exchange capacity