

Geostatistical Analysis of Soil Fertility Status in Part of Nigeria's Dryland

Mohammed Ahmed^{1*}, Juliana Aduku Nekeche² and Amatullah Sadiq Yahaya³

^{1,2}Department of Geography Bayero University Kano

³National Space Research Agency (NASRDA).

mahmad.geog@buk.edu.ng^{1*}, jeaaduku@gmail.com²,
amatullahsadiqyahaya@gmail.com³

*Corresponding Author

Abstract

Majority of the farmers in the drylands of Northern Nigeria cultivates small pieces of land that are < 2ha, with different soil management practices coupled with low distribution of soil fertility has not been documented at global scale. The main objective of this study is to assess the spatial distribution soil fertility using geostatistical approach. Soil samples were taken for pH, organic carbon, nitrogen, phosphorous and potassium at 11 random locations at the depth of 0 – 20cm with the help of a GPS. The soil was analyzed in the soil lab and the result were imputed into GIS environment for the spatial distribution using semivariogram and co-kriging. The result shows that there are low concentration of N, P, and K at the northern part while OC at the southeastern part of the area, however the distribution of pH indicated an opposite or negative distribution compared with the other parameters. The result of the semi-variogram, for Nitrogen, Phosphorus, Potassium, Organic carbon and pH indicated that Gaussian, Circular, Exponential, Tetrasphericals and Stable respectively. The spatial dependency for N, P, OC and Soil pH are showing weak dependency but K indicating a strong spatial dependency. This implies that N, P, OC and pH are all affected with management practices such as tilling, harrowing, nature of cropping which includes mixed cropping and fertilizer application. The study concluded that the use of geostatistics can be applied within the larger scale which can give a guide for fertilizer application and recommended for site specific nutrient analysis.

Keywords: Geostatistics, Semi-variogram, soil fertility, GIS

1. Introduction

Nigeria's dryland has been dominated with cereal cultivation for more than decades, this resulted nutrient mining when this problem persists, it resulted to lowering the soil nutrients which can affect crop production if not properly manage (Kamaluddin *et al.*, 2020). Though, on the other hand other factors under natural conditions may leads to low distribution of soil nutrients that are under agricultural (Atreya *et al.* 2008). Majority of the farmers in these areas are small holder farmers that cultivate less than 2ha coupled with continues cultivation of cereal crops which are nutrient demanding contributed in draining some of the important nutrients in the soil without proper management (Muhammad *et al.*, 2022). However, the area falls within Kano Close settled zone which is part of the dryland areas and have indicated to suffer from soil nutrients depletion which has been documented from different studies (Ahmed *et al.*, 2015).

In trying to achieve food security in this area, there is need to rise in the grain per capital in Nigeria especially in the north where there is intense grain cultivation. However, the cost of food items has increased to about 100% in the recent time (Ajayi, 2015), coupled with the population explosion which has been projected by 2030 to have taken most of the cropland (d'Amour *et al.*, 2017). This requires intensive analysis in order to have the soil information so as to have a picture of the general problem at larger scale rather than looking at it in a global perspective. Several approaches have been applied in the evaluation and detection of soil problems

from global to local scales which are significant fact to be documented. Some of these studies are experimentations which represent a location that lack spatial entity and are later extrapolated or are spatially distributed representing a large area.

A lot of empirical findings has shown that the Nigeria's drylands has been affected by low soil nutrients, degradation and poor soil management practices (Nishant *et al.*, 2014; Aminu and Jaiyeoba, 2015; Olateju *et al.*, 2015; Oloyede *et al.*, 2015; Adeyolanu *et al.*, 2017). While other studies are on soil quality, which has indicated to affect yield and longtime cultivation of cereal crop could resulted to lowering the performance and productivity (Ezeaku, 2015; Garba, 2017; Jimoh *et al.*, 2018) and the recent study on soil nutrient balance requirement for maize in part of the Nigerian dryland (Shehu *et al.*, 2019; Aliyu *et al.*, 2022). Other authors worked on soil fertility classification, constraints on sorghum production, soil properties and effect on cropping and nutrient response for maize (Okorie, *et al.*, 2020; Oklo *et al.*, 2021; Muhammad *et al.*, 2022).

Though, several studies were conducted using Geostatistical approaches around the globe. Like mapping and quantification of the distribution soil nutrient using fuzzy expert system for different crops (Singh and Sharma, 2014; Vinh *et al.*, 2017; Ogunleye *et al.* 2018; Leena *et al.*, 2021; Abd El-Hady *et al.*, 2018; Kingsley *et al.*, 2022; Zheng *et al.*, 2022). Other researches mapped out soil nutrients (Mary *et al.*, 2016) and semivariograms and geostatistical techniques (Kamal *et al.*, 2016; Obroślak and Dorozhynskyy 2017; Panday 2018). Analytical Hierarchy Process (AHP) and Multicriteria Evaluation Criteria Analysis (MCDA) and capability classification (Lawrence *et al.*, 2020; Basavaraj *et al.*, 2020; Anthony *et al.*, 2021; El Behairy *et al.*, 2022; Ahmed and El-Husseiny, 2022).

Insufficient and inadequate spatial information on soil fertility at larger scales (within a localize area) is among the major limiting factors to agricultural development for smallholder farmer in dryland areas (Ahmed, 2021). Studies in the Nigeria's dryland concentrated mostly on fuzzy logic (Ahmed, 2015) soil nutrient variation (Ahmed, Adamu and Mohammed 2015; Danjuma *et al.*, 2020). The recent finding of Kamaluddin *et al.*, (2020) on soil fertility management for site specific for maize production in part of the dryland areas of Nigeria indicated lower fertility indicators distributed across the area. This shows the need to analyze the spatial variation of soil within the local environment (or at larger scale) for local farmers. It is on this background that, this study tends to examine the spatial distribution of soil nutrients in part of Gwarzo Local Government Area Kano State-Nigeria. Therefore, the main objective of this paper is to analyze the spatial distribution of soil fertility and using geostatistical analysis.

2. Materials and Methods

2.1 Study Area

The study area (Figure 1) is at Getso village in Gwarzo Local Government Area of Kano State. It is located between Latitude 11.88° 33"N to 11.88°349"N of the equator and Longitude of 7.96°93"E to 7.96° 843"E of the Prime Meridian. The area falls within the tropical wet and dry type coded as Aw (Tropical wet Savannah) according to Koppen's classification and have characteristics as a typical of West African savannah; temperature in the region is generally throughout the year (Ibrahim, 2011).

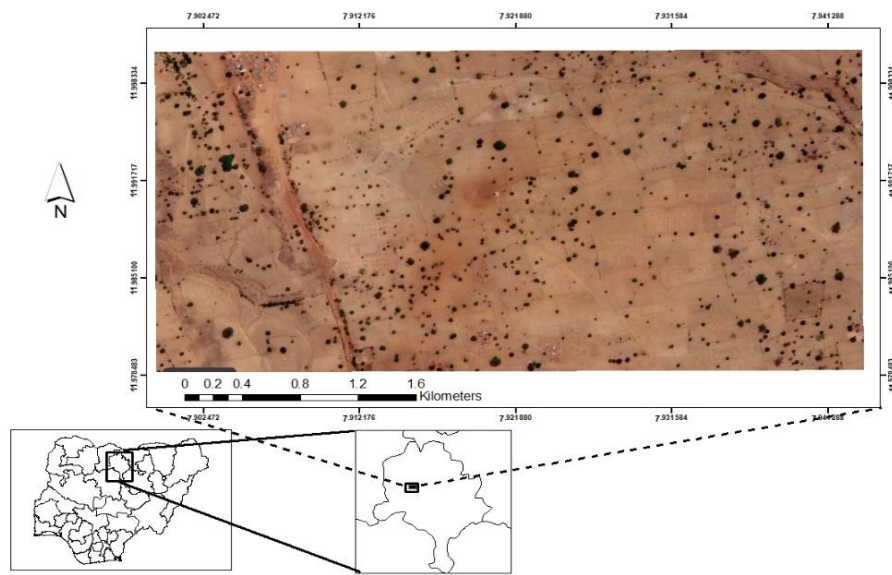


Figure. 1 Study area

The annual rainfall is about 1000mm in the southern part of Kano where the northern extreme, the annual value received is lower than 1000mm especially toward the vicinity of desert. The soils of the area are dominated by sandy and high bulk density. Pre-Cambrian rock of the basement complex which comprises of gneiss amphibolite's, marbles and the later granites which underlie large part of Nigeria including 70% of the Kano region (Olofin, 1985). Trees are composed of variety of species hardly taller than 20m ranging from baobab of different types of acacias, for example *Acacia Albidspp*, *Acacia Nitoticaspp* and *Acacia seyal spp*. The vegetation has been characterized to be the dry guinea on the southern fringe in Sudan on larger part of the region (Olofin, 1987; Dakata and Yelwa 2012). These areas are verse with low rainfall, soil moisture and scanty trees distributed which give the advantage of cultivating some short season crops such as cereals and what characterized the area as dryland (Danjuma *et al.*, 2020).

3. Research Methods

3.1 Types of Data and Sources of Data

The type of data used in this research work were qualitative and quantitative type of data which is the soil parameters which include soil pH, organic carbon, nitrogen, phosphorous and potassium. This study utilized both primary and secondary data as its sources of data collection. The primary sources include mainly field data i.e measurement of landscape characteristics and the laboratory results of the soil samples collected from the field (physical and chemical properties). The secondary source of data constitutes mainly on the use of satellite image (i.e., Google earth image), others materials were sourced from journals and articles

4. Soil Sampling

Images of the study area was downloaded from Google Earth; the area was grouped according to crop type and management. Four (4) composite soil samples were taken within the radius of 5meters and mixed for all the locations. 11 random samples were taken in the area at the depth of 0-20cm using the Global Position System (GPS) in recording the locations and other attributes such as type of crop and management practiced.

5. Soil Laboratory Analysis

The soil pH was determined in a glass electrode pH meter (Mclean, 1965), while the total nitrogen was determined by the macro-Kjeldahl digestion methods (Skjemstad and Reeve, 1976). Phosphorous (p) content

was determined using the colourimeter (CECIL CE 373) method using the sodium hydrogen carbonate extraction in line with Bray and Kurtz (1945) method. potassium (K), were determined using a flame photometer and atomic absorption spectrophotometer respectively, Organic Carbon content of the soil was determined as described by Nelson and Sommers, (1982).

6. Geostatistical Analysis

The data were used to map the distribution of soil properties and analysis of variability using semivariogram tool in ARC GIS 10.5 statistical software to depict spatial autocorrelation of the measured sampling locations. Ordinary kriging was applied in the interpolation procedure as presented in Equation (1). Geostatistical analysis of the soil parameters was performed in GIS environment. Ordinary kriging procedure was used to estimate interpolated values of each soil parameter at non-measured points based on Equation (1) (Krig and Wijsian, 1981).

$$\gamma(h) = 1/2N(h) \sum_{i=1}^{N(h)} [Z((xi) - Z (xi + h))]^2 \tag{1}$$

where $\gamma(h)$ denotes semivariance at lag distance (h), $N(h)$ is the number of measured pairs separated by (h), and $Z(x_i)$ and $Z(x_i + h)$ are sampled measured values at i th sampling point separated by vector (h).

The best fitted models were selected for the parameters (N, P, K, OC and pH). The evaluation of the interpolations was as the result of the validation indices using Root Mean Square Error (RMSE) as presented in Equation (2).

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (M_i - P_i)^2}{n}} \tag{2}$$

7. Result and Discussion

The results were entered into the GIS environment to analyzed the spatial distribution. Semivariogram was used for co-kriging to select the best fitted model for the distribution and to determine the probable effect of the distribution (Natural or Anthropogenic).

7.1 Spatial Distribution

The distribution of Nitrogen indicated low with 32.22% especially at the North-west of the area and also small portions in the north and south, while concentration of moderate with 48.33% at central part and high with 19.45% at the central and southern part of the area (Table 1).

Table 1: Area (ha) of parameters

Parameter	Low(ha)	%	Moderate (ha)	%	High(ha)	%
Nitrogen	1.64	32.22	2.46	48.33	0.99	19.45
Phosphorus	2.54	49.90	2.14	42.04	0.42	2.75
Potassium	1.64	32.22	2.46	48.33	0.99	19.45
Organic carbon	2.54	49.90	1.53	41.85	0.36	8.25
Soil pH	0.79	15.52	3.19	62.67	1.11	21.81

Distribution of Phosphorus shows a low with 49.90% at the east and north eastern part, moderate of 42.04% much distribution showing domination in most of the area and high with 2.75% at the central part.

The result of Potassium indicated a low with 32.22% at the northeastern area, moderate with 48.33% and high with 19.45% at the southeastern part. The concentration of the Organic carbon for low is within 49.90% at the southeastern part and moderate with 41.85% distributed across the area, while high at 8.25% within the central part. The pH in the area is within low with 15.52% at the central and eastern part while a moderate with 62.67% occurred at the in almost all the area and high with 21.81% northeastern part, however the distribution of pH indicated an opposite or negative distribution compared with the other parameters (NPK, and OC) as shown in figure 2 similar findings were shown in Kamaluddin et al., (2020) from a matrix of correlation showing a negative result on soil pH, SOC, and Ntot within the study area.

From the findings, the area is dominated with low concentration of soil nutrients which sometimes has linked to low vegetation cover, low moisture and rainfall among other factors. Therefore, the study corroborates with many findings within the Nigeria’s dryland that shows very low to soil nutrients (Ahmed *et al.*, 2015; Ahmed 2015; Danjuma *et al.*, 2020; Kamaluddin *et al.*, 2020).

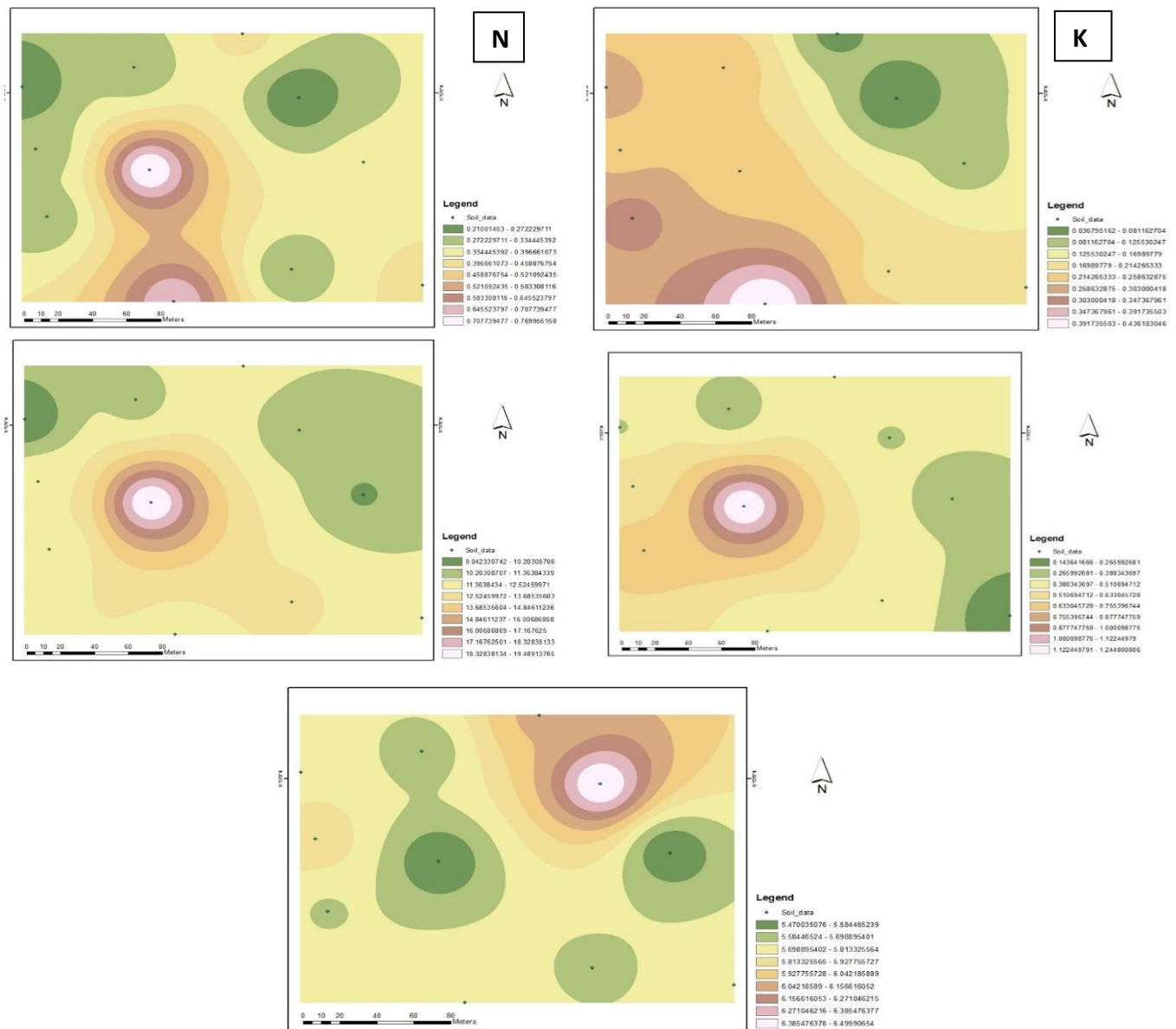


Figure 2: Spatial Distribution of Soil Parameters

7.2 Suitable Models and the Semi-Variogram

The analysis shows the suitable models and the semi-variogram, which is called the nugget, range, and partial sill for each parameter (Nitrogen, Phosphorus Potassium, Organic carbon and Soil pH data set). The result indicated that best fit model for the parameters were Gaussian, Circular, Exponential, Tetrasphericals and Stable respectively (Table 2).

Table 2: Semi-variogram

Variables	Depth (m)	Lag size	Model	Nugget (Co)	Sill(Co + C)	Spatial dependency (Co/Co+C)	Partial sill (Co)	Range	RMSE
N	0-30	0.00035	Gaussian	0.0356	0.0356	1	0	0.004183	0.19908
P	0-30	0.0003	Circular	7.2609	7.260	1	0	0.004183	2.84167
K	0-30	0.00029	Exponential	0	0.0205	0	0.0205	0.003517	0.09786
OC	0-30	0.0003	Tetraspherical	0.0822	0.082	1	0	0.00418	0.3023
pH	0-30	0.0003	Stable	0.0845	0.084	1	0	0.00418	0.3065

Also, infer that experimental data had a positive nugget effect (C_o) for all the result. The nugget/sill ratio (C_o/C_o+C) define the spatial dependency. The variables are considered as strong spatial dependence when is less than 0.25 and weak spatial dependency when is between 0.25-0.75 and a very weak spatial dependency above 0.75 (Cambardella *et al.*, 1994; Tripathi *et al.*, 2015). The result indicated a weak spatial dependency for N, P, OC and pH, but K distribution with strong spatial dependency of 0. This implies that N, P, Organic carbon and soil pH are all affected with management practices such as tilling, harrowing, nature of cropping which includes mixed cropping and fertilizer application which has been indicated by Ahmed (2021) and majority of the farmers in the area cultivates less than 2ha which includes pearl corn, millet, maize, beans, groundnut, and okro. Dissimilar result in Kamaluddin *et al.*, (2020) that shows a high spatial dependence across the area study area for N, P, OC and pH, with similar result for K as the result of natural occurrence of such element within the dryland areas. The dominance of K according to Ahmed, (2021) is readily available in the Savannah soils as the result of effect of “winddrift” which at the end it will form a “duricrust” of ironfan within the surface layer and harden and thereby making the P and N to be low in natural form.

8. Conclusion and Recommendation

Geospatial technique of soil nutrients in the area shows a low concentration in all the parameters (N, P, OC and K) with the exception of pH and they are affected with anthropogenic factors as indicated by the Semivariogram model such as nature of soil management practice, cropping systems and the distribution of K affected by natural factors such as geology and climate among others. The study recommended for proper fertilizer application within small area especially in the challenging dryland environment. The concentration of soil parameters in the area are more to a certain location (west-central to southwestern part). Therefore, study recommended for proper site-specific fertilizer application, instead of the normal blanket systems that has been practiced in most of the smallholder farmers. Farmers in the area should be applying organic manure so as to enhance the soil microbial activities. Also, the application of fertilizer (NPK) should be 25:15:05 due to high abundance of K.

Acknowledgment

The authors wish to express their special thanks to Mr. Aduku Nekeche of the Department of Civil Engineering, Bayero University Kano for the assistance during the soil and water analysis

References

- Abd El-Hady, A.M., Abdelaty, E.F. and Salama, A.E. (2018) GIS-Mapping of Soil Available Plant Nutrients (Potentiality, Gradient, Aniso-tropy). *Open Journal of Soil Science*, 8, 315-329. <https://doi.org/10.4236/ojss.2018.812023>
- Adeyolanu O. D., Are K. S., Adelana A. O., Denton1 O. A and. Oluwatosin G. A (2017) Characterization, Suitability Evaluation and Soil Quality Assessment of Three Soils of Sedimentary Formation for Sustainable Crop Production *Journal of Agriculture and Ecology Research International*11(2): 1-10, Article no.JAERI.31943
- Ahmed M. (2015) The Use of Fuzzy Logic and Geostatistical Techniques for Spatialization of Soil Texture in Part of Kano Close Settled Zone Kano State, Nigeria. *International Journal of Agriculture, Forestry and Fisheries*. Vol. 3, No. 3, pp. 115-122.
- Ahmed M. (2021) Geospatial Assessment of Soil Quality and Cropping Systems in Parts of the Dryland of Northern Nigeria, *PhD. Theses. Submitted to the Department of Geography Bayero University, Kano.*
- Ahmed M., Adamu G. K, and M.U. Mohammed (2015) Spatial Variation of Nitrogen, Phosphorus And Potassium For Fertilizer Usage in Part of Kano Drylands. *Kaduna Journal of Geography*. Vol. 1 No 1. 33 – 49.
- Ahmed S. Abuzaid and Ahmed M. El-Husseiny (2022) Modeling crop suitability under micro irrigation using a hybrid AHP-GIS approach *Arabian Journal of Geosciences*.15: 1217
- Ajayi A. S. (2015) Land degradation and the sustainability of agricultural production in Nigeria: A review *Journal of Soil Science and Environmental Management* Vol. 6(9), pp. 234-240, DOI 10.5897/JSSEM15.0507
- Aliyu, K T Kamara A. Y, Huising E J, Jibrin J M, Shehu B M, Rurinda J, Adam A M, Mohammed I B and Vanlauwe B (2022) Maize nutrient yield response and requirement in the maize belt of Nigeria. *Environ. Res. Lett.* 17: 064025
- Aminu, Z. and Jaiyeoba, I. A (2015) An Assessment of Soil Degradation in Zaria Area, Kaduna State, Nigeria *Ife Research Publications in Geography* 13 27 – 37
- Anthony T, Bolarinwa S, Temitope O, and Samuel B. (2021) Geospatial assessment of wetland soils for rice production in Ajibode using geospatial techniques. *Open Geosciences*; 13: 310–320
- Atreya KS, Sharma RM, Bajracharya NP (2008) Developing a sustainable agro-system for central Nepal using reduced tillage and straw mulching. *J Environ Manag* 88:547–555.
- Basavaraj Biradar, Jayadeva HM, Channakeshava S, Geetha KN, Manjanagouda S Sannagoudar, Pavan AS and Prakash KN (2020) Assessment of soil fertility through GIS techniques and thematic mapping in micro watershed of Hassan, Karnataka. *Journal of Pharmacognosy and Phytochemistry*. 9(4): 3218-3228
- Bray, R.H. and Kurtz, L.T. (1945) Determination of Total Organic and Available Forms of Phosphorus in Soils. *Soil Science*, 59, 39-45. <http://dx.doi.org/10.1097/00010694-194501000-00006>
- Cambardella, C.A., Karlen, D.L., (2012). Spatial analysis of soil fertility parameters. *Precision Agriculture* 1(1): 5-14.
- Cambardella, C.A.; Moorman, T.B.; Novak, J.M.; Parkin, T.B.; Turco, R.F.; Konopka, A.E. (1994), Field-scale variability of soil properties in central Iowa soils. *Am. Soil Sci. Soc. J.* 58, 1501–1511.
- Dakata F.A and Velwa S.A (2012). An assessment of mean and inter-seasonal variation during growing season Across Kano Region, Nigeria using normalized difference vegetation index derived from Spot Satellite Data. *Global advanced Research Journal social of science* Vol. 1(3), 59.
- d'Amour C. B., Reitsm F. A, Giovanni B, Karen C. Seto (2017) Future urban land expansion and implications for global croplands; An integrated socioecological approach to land- use intensity: Analyzing and mapping biophysical stocks/flows and their socioeconomic drivers, Urbanization and Resilient Food security. *Proceedings of the National Academy of Sciences* 114(34):8939–8944.
- Danjuma M. N Zakariya M., Ahmed M and Mafara S. A (2020) Spatial Variability of Soil Properties around Baturiya Sanctuary, Jigawa State, Nigeria. *Journal of Techno Social* Vol. 12 No. 1 p. 36-45.

- El Behairy, R.A.; El Baroudy, A.A.; Ibrahim, M.M.; Mohamed, E.S.; Kucher, D.E.; Shokr, M.S. (2022) Assessment of Soil Capability and Crop Suitability Using Integrated Multivariate and GIS Approaches toward Agricultural Sustainability. *Land*, 11, 1027. <https://doi.org/10.3390/land11071027>
- Ezeaku P. I. (2015) Evaluation of agro-ecological approach to soil quality assessment for sustainable land use and management systems. Vol. 10(15), pp. 501-512, 15 DOI: 10.5897/SRE10.404
- Garba Y. I. (2017) Assessment of Soil Quality under Long-Term Rice-Based Cropping System in Paki, Kaduna State, Nigeria *Asian Journal of Applied Sciences* (ISSN: 2321 – 0893) Volume 05 – Issue 01,
- Ibrahim, A. (2011). Assessment of The Urban Canopy Heat Island (UCHI) of Kano Metropolis During Dry Season. Ahmadu Bello University (ABU), Zaria: *Paper Presented at International Conference on Climate Change Impacts, Risk and Opportunities*.
- Jimoh A. I Aliyu J, Sabo A.T. and Yusuf Y.O (2018) Land Suitability Evaluation of Kubanni Floodplain for Rice Production in Zaria, Kaduna State, Nigeria. *Nigerian Journal of Basic and Applied Science* (June, 26(1): 46-54.
- Kamal K., Arora, K. and Hariprasad, S., (2016): Geostatistical analysis of soil moisture distribution in a part of Solani River catchment. *Applied Water Science*. Vol 6, Issue 1, pp 25–34.
- Kamaluddin T. Aliyu, Alpha Y. Kamara, Jibrin M. Jibrin , Jeroen E. Huising , Bello M. Shehu , Julius B. Adewopo , Ibrahim B. Mohammed , Reuben Solomon , Adam M. Adam and Ayuba M. Samndi (2020) Delineation of Soil Fertility Management Zones for Site-specific Nutrient Management in the Maize Belt Region of Nigeria. *Sustainability* 9010; doi:10.3390/su1221901
- Kingsley J. , Yassine B., Isong A . I., Lahcen H, Rachid R, Ndiye M. K., Prince C. A, Vit P. and Tereza Z. (2022) Mapping soil nutrients via different covariates combinations: theory and an example from Morocco. *Ecological Processes* 11:23 <https://doi.org/10.1186/s13717-022-00368-y>
- Krig, D.G. Lognormal-de Wijsian (1981). In *Geostatistics for Ore Evaluation*; Printpak (Cape) Ltd.: Johannesburg, South Africa.
- Lawrence T. Nanganoa, Francis A. Ngome, Christopher Suh, and Simon D. Basga (2020) Assessing Soil Nutrients Variability and Adequacy for the Cultivation of Maize, Cassava, and Sorghum in Selected Agroecological Zones of Cameroon. *International Journal of Agronomy*. Volume, 20 pages <https://doi.org/10.1155/2020/8887318>
- Leena H.U., Premasudha B.G., Panneerselvam S., and Basavaraja P.K. (2021) Pedometric mapping for soil fertility management A case study. *Journal of the Saudi Society of Agricultural Sciences* 20, 128–135
- Mary A, Alfred A. D., Mathias F., and Robert C. A., (2016): Geospatial approach to study the spatial distribution of major soil nutrients in the Northern region of Ghana. *Journal of Cogent Geoscience*. Volume 2, - Issue 1.
- Muhammad A. Y., Hussein S., Baloua N., Chris O. Ojiewo and Gideon D. (2022) Sorghum production in Nigeria: opportunities, constraints, and recommendations, *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, 72:1, 660-672, DOI: 10.1080/09064710.2022.2047771
- Nelson D.W. and Sommers, I.E. (1982) A rapid and Accurate Procedure for Estimation of Organic Carbon in Soils. *Proceedings of Indian Academy of Science*, 84:456482
- Nishant K, Sinha M Mohanty, Bharat P Meena, Hiranmoy Das, Usha K Chopra and Anil K Singh (2014) Soil quality indicators under continuous cropping systems in the arid ecosystem of India. *Academic Journals* Vol. 9(2), pp. 285 293
- Obroślak R., and Dorozhynskyy, O. (2017). Selection of a semivariogram model in the study of spatial distribution of soil moisture. *Journal of Water and Land Development*. No. 35 p. 161–166. DOI: 10.1515/jwld-2017-0080.
- Ogunleye, G. O., Fashoto, S. G., Petros M., and Arekete, S. A. (2018): Fuzzy Logic Tool to Forecast Soil Fertility in Nigeria. *The Scientific World Journal*. P.7.
- Oklo, A.D., Armstrong, I.A., Idoko, O.M., Iningev, T.S., Emmanuel, A.A. and Oklo, R.O. (2021) Assessment of Soil Fertility in Terms of Essential Nutrients Contents in the Lower Benue River Basin Development Authority Project Sites, Benue State, Nigeria. *Open Access Library Journal*, 8: e7222. <https://doi.org/10.4236/oalib.1107222>

- Okorie, F.C., Chinyere, C.-N, Ifeanyi, J.O. and Lazarus, C. (2020) Geospatial Analysis of Soil Properties and Their Effects on Maize and Cassava Production in Ohaji/Egbema Imo State, Nigeria. *Open Access Library Journal*, 7: e6259. <https://doi.org/10.4236/oalib.1106259>
- Olateju D. A and Ayoade O. O. (2016), Comparison of qualitative and quantitative approaches to soil quality assessment for agricultural purposes in South-western Nigeria *Cogent Food & Agriculture* 2: 1149914 <http://dx.doi.org/10.1080/23311932.2016.1149914>
- Olofin E. (1987) Some aspect of the physical geography of the Kano region and related human responses departmental lecture note service; geography department Bayero University, *Debris standard printer*, Kano Nigeria.
- Oloyede, A.O; Muhammad-Lawal, A; Ayinde, O.E; and Omotesho, K. F (2015) Determinant of Soil Management Practices in Cereal Based Production Systems among Small-Scale Farmers In Kwara State. *Journal of Tropical Agriculture, Food, Environment and Extension* Volume 14 Number 2 pp. 18 – 23
- Panda, S.C., (2010): Soil Management and Organic Farming. Agrobios, *Bharat Printing Press, Jodhpur, India*. 462p.
- Panday D, Maharjan B, Chalise D, Shrestha RK, Twanabasu B (2018) Digital soil mapping in the Bara district of Nepal using kriging tool in ArcGIS. *PLoS ONE* 13(10):
- Shehu, B.M.; Bassam, A.L.; Jibrin, M.J.; Alpha, Y.K.; Ibrahim, B.M.; Jairos, R.; Shamie, Z.; Peter, C.; Vanlauwe, B.; Adam, M.A. (2019) Balanced nutrient requirements for maize in the Northern Nigerian Savanna: Parameterization and validation of QUEFTS model. *Field Crop. Res.*, 241, 107585.
- Singh H. and Sharma, N. (2014): “Optimization of fertilizer rates for wheat crop using fuzzy expert system,” *International Journal of Computer Applications*, vol. 100, no. 1, pp. 36–40., View at Publisher · View at Google Scholar.
- Skjemstad, J.O., and Reeve, R. (1976) “The determination of nitrogen in soils by rapid high- temperature Kjeldahl digestion and autoanalysis”, *Commun. Soil Sci. Plant Anal.*, 7, 229-239.
- Tripathi, R.; Nayak, A.K.; Mohammad, S.; Lal, B.; Priyanka, G.; Raja, R.; Mohanty, S.; Anjani, K.; Panda, B.B.; Sahoo, R.N. (2015). Delineation of soil management zones for a rice cultivated area in eastern India using fuzzy clustering. *Catena*, 133, 128–136.
- Vinh B., Karl, S., and Gerhard, C. (2014): A fuzzy logic slope-form system for predictive soil mapping of a landscape-scale area with strong relief conditions. *Journal of Science Direct*. Vol. 115. Pp 135-146.
- Zheng C, Yang X, Liu Z, Liu K, Huang Y. (2022). Spatial distribution of soil nutrients and evaluation of cultivated land in Xuwen county. *PeerJ* 10:e13239 <http://doi.org/10.7717/peerj.13239>