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Christopher Oche Albert
Alaga Taofeek Abayomi
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***Christopher Oche Albert, Alaga Taofeek Abayomi, Ogbole Owoicho John**

Cooperative Information Network (COPINE), Advanced Space Technology Application Laboratory (ASTAL), National Space Research and Development Agency (NASRDA), P.M.B 022, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria.

*Corresponding Author's Email: link2oche @yahoo .com

ABSTRACT

Sokoto State is in Northwestern Nigeria. Geologically, it represents parts of the south eastern sector of the Iullemmedan basin and it contained important phosphorite deposits. Field study and sampling from the type locality in Sokoto cement industry indicates that the phosphate rock varies in size and colour, occurring in beds and disseminations majorly in the Sokoto Group of sediments. The field data, geology, pedology and elevation data for Sokoto state was reclassified using geospatial analysis to access their suitability for phosphate rock prospecting, ranking from the highly suitable to the highly unsuitable. These data was now incorporated as one for spatial analysis and together with result from geochemical analysis of the phosphates rock was used to produce the suitability map for phosphates rock in Sokoto State. Result indicates that, Gwadabawa, Dange, Wurno, Shagari, Wamakko, Sokoto North, Sokoto South, Kware, Bodinga and Illela Local Government Areas (LGA's) provides major sites for phosphates prospecting and therefore very suitable. Geochemistry indicates average phosphates (P_2O_5) contents to be 33.89%; a very acceptable grade for raw phosphate rock. Final validation of study is based on the geospatial overlay of the sampled area and the suitable area on the map which gave a very good match.

Keywords: Iullemmedan basin, type locality, beds, disseminations, Group of sediments, geospatial analysis, suitability map.

INTRODUCTION

The primary aim of prospecting is location of mineral resources of interest in an area. Phosphate rock or phosphorites refers to mineral assemblage that occurs naturally with an exceptionally high concentration of phosphate minerals, Raw Material Research and Development Council, RMRDC (1995). Most recovered phosphate rocks in the world is used for the manufacture of superphosphate fertilizer and phosphoric acid for the production of compound fertilizer, Food and Agricultural Organization, FAO (2000). The reserve estimate of Sokoto phosphate deposit is five (5) million tonnes, Ministry of Solid Minerals Development, MSMD (2000). The place of fertilizer as input material for agriculture cannot be overemphasized as sustainable agriculture is a key agenda of the government of Nigeria at all levels.

Several data were analyzed using Geographic Information Systems (GIS) techniques and this helps in establishing the suitable areas for phosphates prospecting in Sokoto State. Field sampling leads to analysis and this gives insight on the geochemistry of the phosphate rock and thus average P_2O_5 content known. Exploration and exploitation of the fertilizer mineral resources will boost agricultural production and also save Nigeria's national foreign exchange, which is expended on the importation of rock phosphate.

MATERIAL AND METHOD

Data

Several data was used for this study ranging from geospatial to geology and geochemistry data. All this is as presented in Table 1.

Table 1: Data

S/N	DATA/YEAR	FORMAT	RESOLUTION/SCALE	SOURCE
1	SRTM DEM/1999	Digital	30m	NASA
2	Geology Map/2006	Analogue	1:500 000	NGSA
3	Soil Map/1997	Analogue	1:1 300 000	Wageningen, The Netherlands
4	Google Earth Image/2015	Digital		Digital Globe
5	Geochemistry Data/2006	Analogue		National Steel Council.

Methods

Unique methods were used to locate the suitable areas for phosphate prospecting in Sokoto State. This method includes geology, remote sensing, pedology, field study and also using GIS analysis. And they are all interrelated in achieving the primary objective of this study.

Sokoto State boundary was clipped from the SRTM/DEM map of Nigeria and imputed into the database. Geology and soil map of Nigeria was georeferenced, clipped and digitized as the case may be. Join and relates was done for the Google earth image and field study to get the sample area map. Geochemistry data is from analysis. And all this is now fed into the database. Several maps were now generated from the database such as the elevation of the study area, soil as well as geology map. Spatial analysis was now carried out on the individual map; For example features data were converted to raster for reclassification. Rasters were assigned value based on expert opinion to produce various suitability maps and final suitability map is based on the Boolean and relational mathematical operators. The final validation of site suitability for Sokoto phosphate is base on the geospatial overlay of the sample area map and the suitability map, which gives a very good match (figure 1).

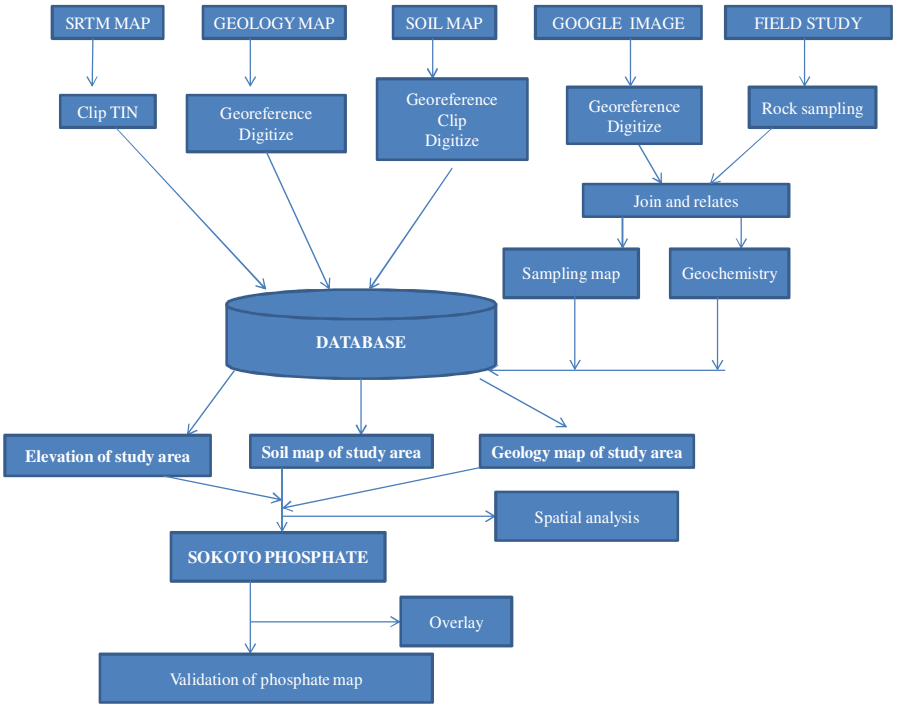

Figure 1: Methodology of study

Study area

The area that forms the scope of this study is Sokoto State, which is a part of the Sokoto basin, northwestern Nigeria. It is bordered to the north by Niger Republic and to the south by Kebbi and Zamfara States of Nigeria (Figure 2). It represents the southeastern sector of the Iullemmenden basin; which is a large synclinal structure trending NE-SE and it extends to Niger Republic, Mali, and Benin Republic. Sokoto basin comprises one tenth of the Iullemmenden basin (Kogbe, 1979). Sokoto State lies approximately between latitude 11°33'42"N and 13°59'7"N and longitude 4°9'36" E and 6°45'33"E.

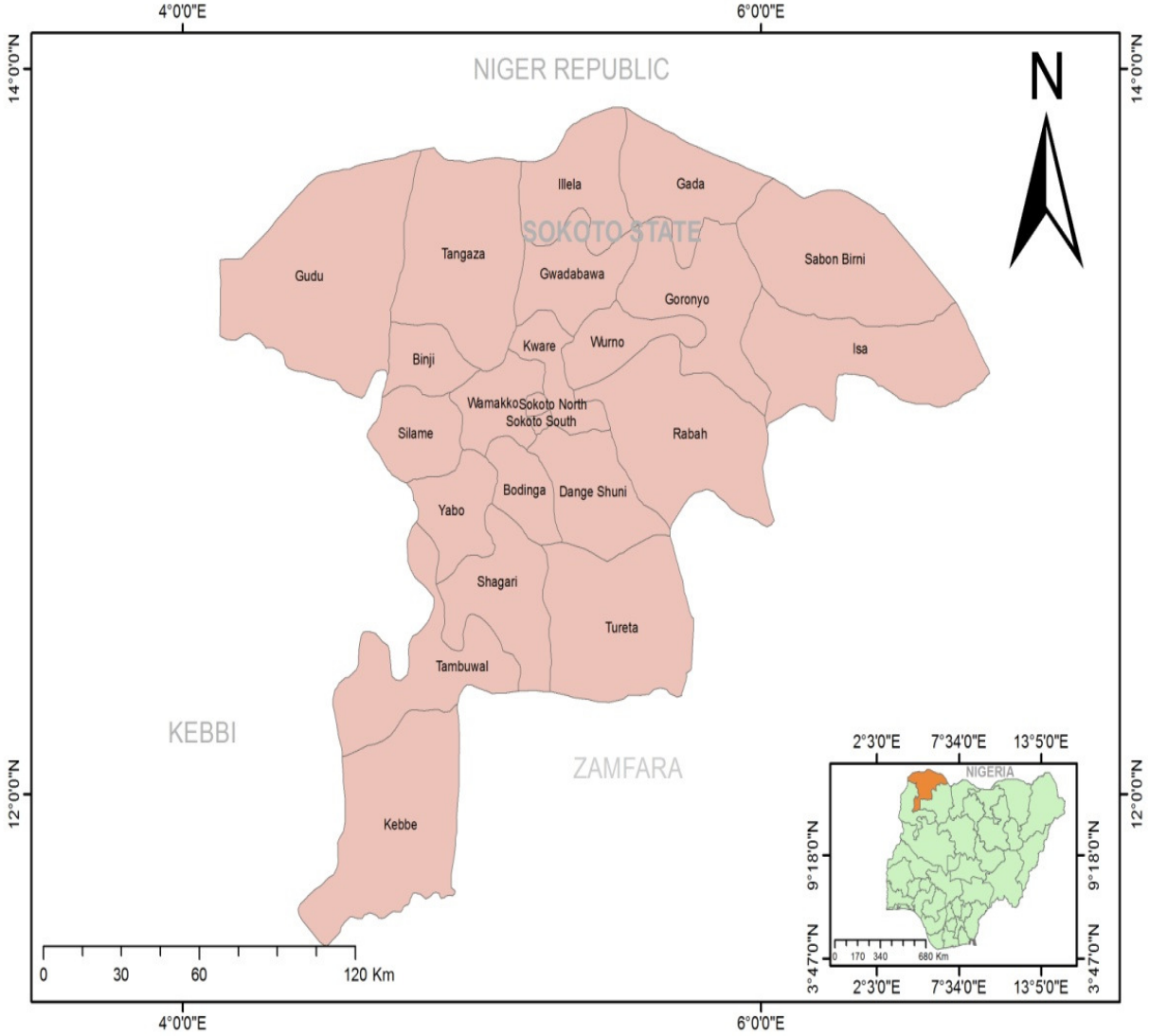

Figure 2: Location of Sokoto State in map of Nigeria (coloured) and Location map of Sokoto

RESULTS AND DISCUSSION

Sample Area

The areas around Sokoto cement company form the major sampling area (figure 3). Samples of phosphates rock was taken from eight different areas, which is also part of the major quarry for limestone rock for the Sokoto cement company. Sokoto State is characterized majorly with bareland and sparse vegetation. Sampling was done from exploration pits, weathered section, mined sites and excavated rubbles.

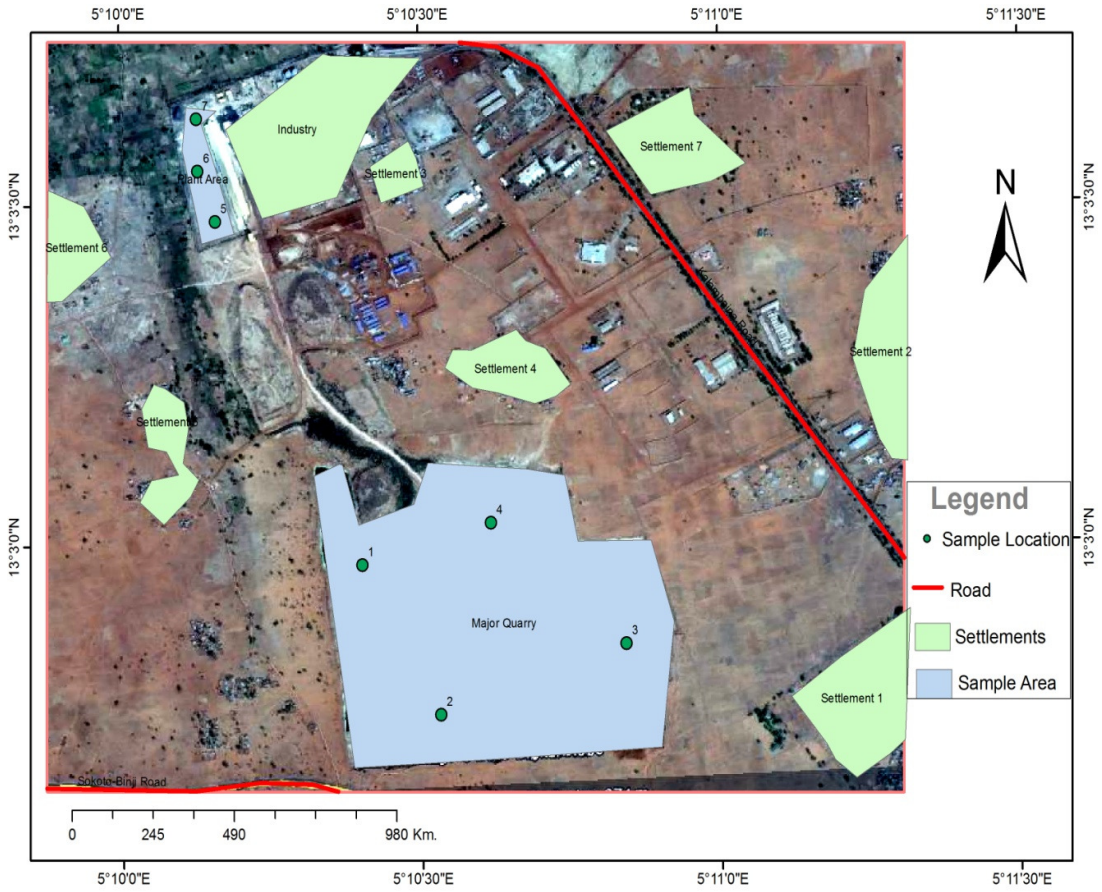

Figure 3: Sample area in Sokoto cement industry as type locality

Geology

Rock type is a primary consideration in prospecting for mineral resources because of the association of mineral to particular rock types or group of rocks. From Field study and existing literature, the phosphate rock of Sokoto State is primarily associated with the Sokoto Group of sediment which comprises of shale, limestone and phosphatic pellets (figure 4).

From the geology map produced for Sokoto State, it is obvious that Kakume and other parts of the southern tip of the map are not major prospective areas for phosphates in Sokoto State as they are mostly associated with basement rock. The most prospective areas geologically are the Sokoto, Dange, Wurno and Shagari areas which are mostly in the central part of the state.

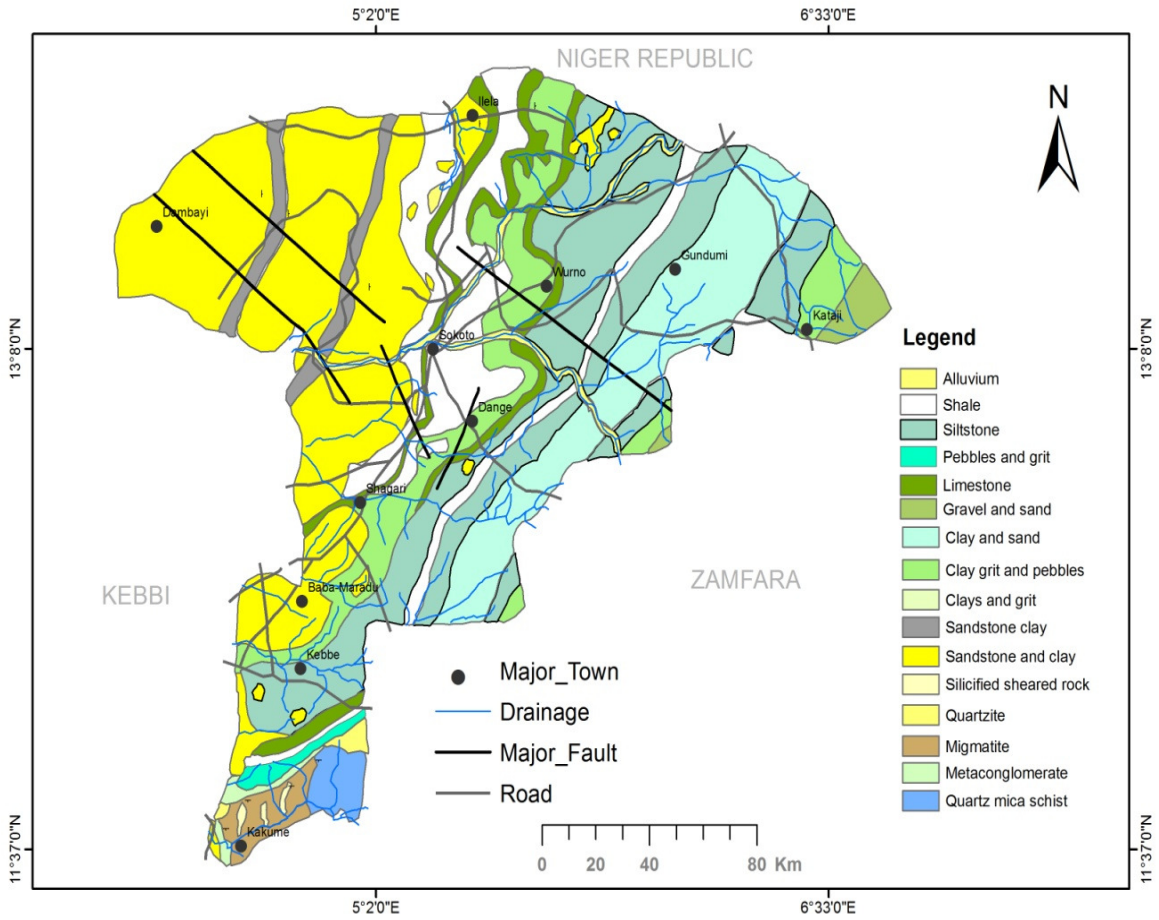

Figure 4: Geology map of Sokoto State

Pedology

A very good assumption in mineral prospecting is that, the surface pedologic manifestation is a function of the subsurface bedrock. For Sokoto State, from the field study, major soil class was identified (figure 5). The arenosols are the most important for phosphate prospecting as they are coarse weakly developed sandy soils with good water volume, but also dry out quickly. This is followed by the fluvisols which are young alluvial deposits in river valleys and old alluvial channels. From the field study, the acrisols and leptosols are not very important prospects for phosphate occurrence.

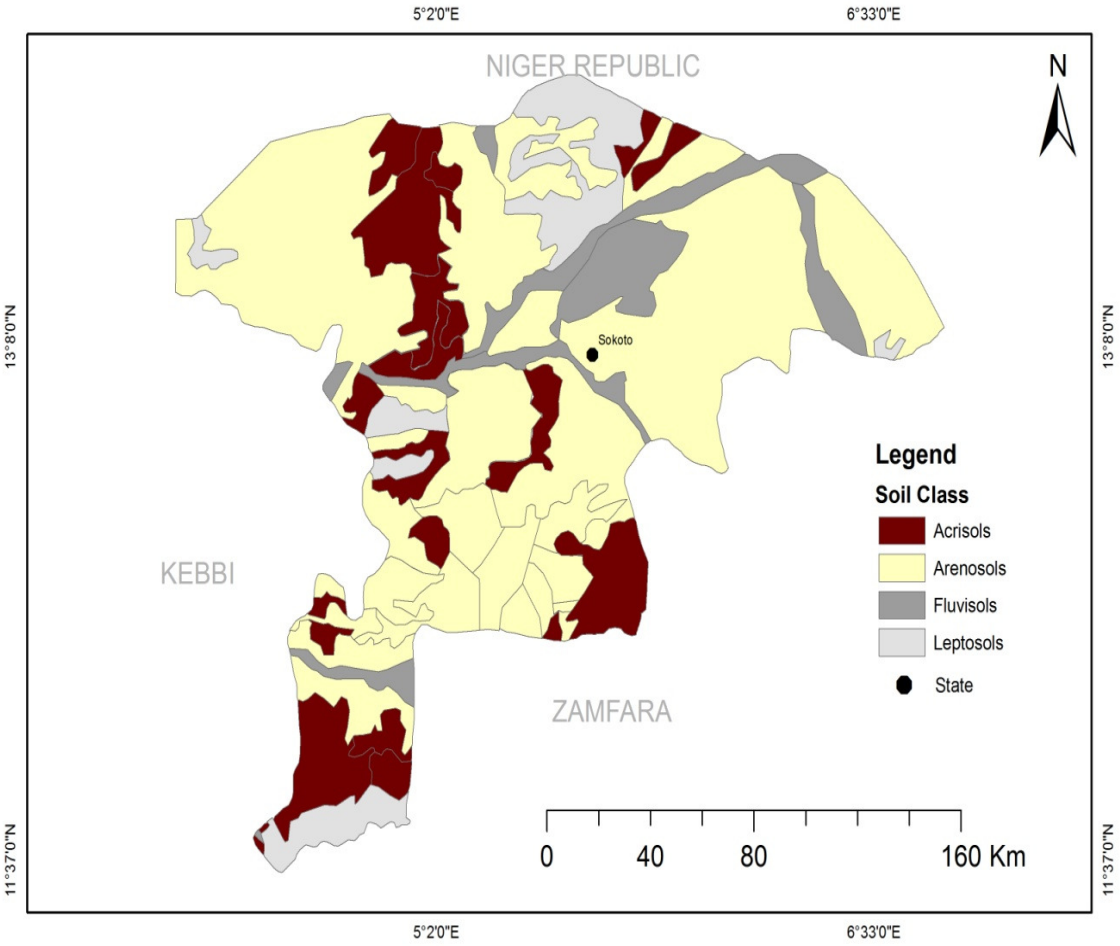

Figure 5: Soil map of Sokoto State

Reclassification

The rock and soil types in Sokoto State was reclassified and assigned value based on their suitability as prospect for phosphates rock. This is based on expert opinion and it gave prospecting areas from the highly suitable to the highly unsuitable areas. For rock types, shale was assigned the highest value followed by limestone, pebble and grits, sandstone and clay and the least value is clay and grits. Those basement rocks that are not prospecting areas for phosphates were restricted in the spatial analysis. For the soil class, the arenosols was given the highest value followed by fluvisols, leptosols and acrisols.

This geospatial analysis now gave relative suitability map for rock type and soil type (figure 6 and 7).

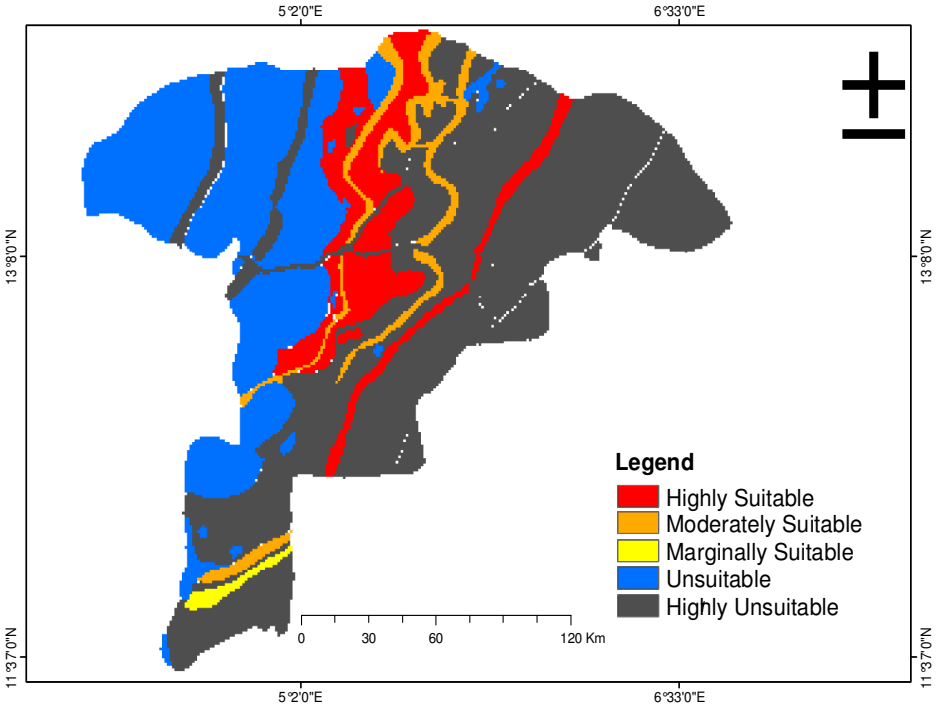

Figure 6: Reclassified rock types based on suitability

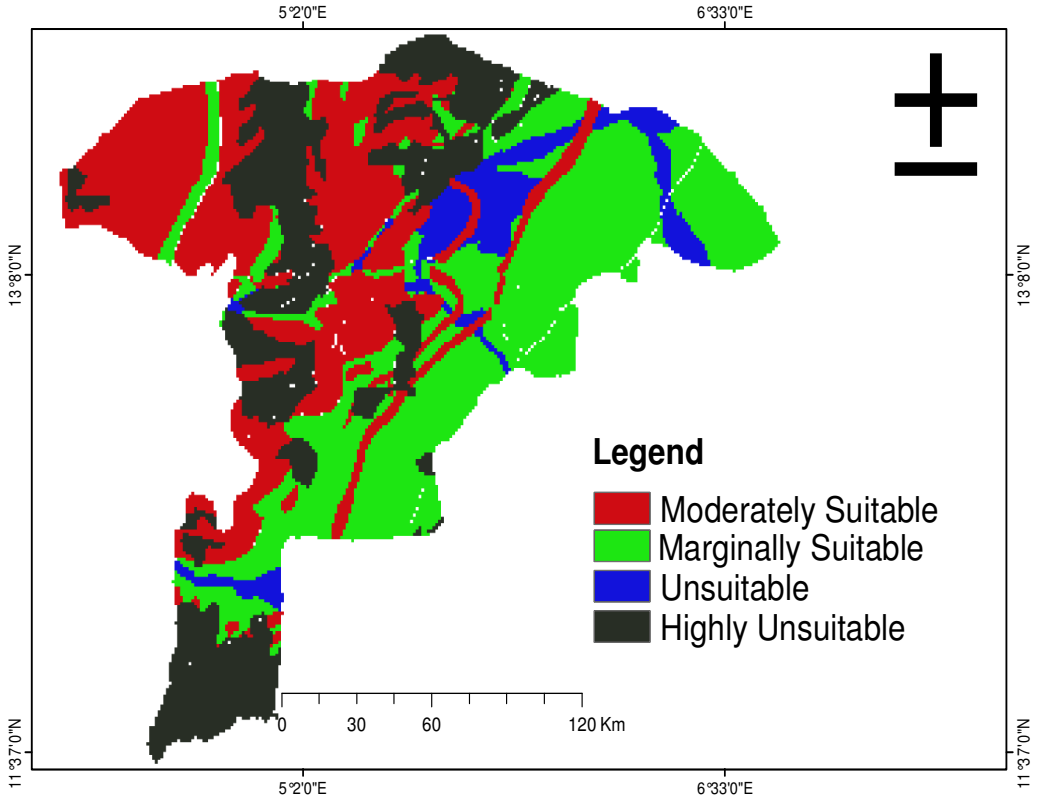

Figure 7: Reclassified soil types based on suitability

The phosphate suitability map for Sokoto State is based on the Boolean and relational mathematical operators that apply sets of mathematical operations to the values in two or more input rasters. If a condition is true it is

assigned one (1) and if false it is assigned zero (0) to determine the suitable and non suitable areas in Sokoto State. This was done for the available data; that is rock, soil, geochemistry, elevation etc., to be able to get the suitable areas for phosphate prospecting in Sokoto State (figure 8).

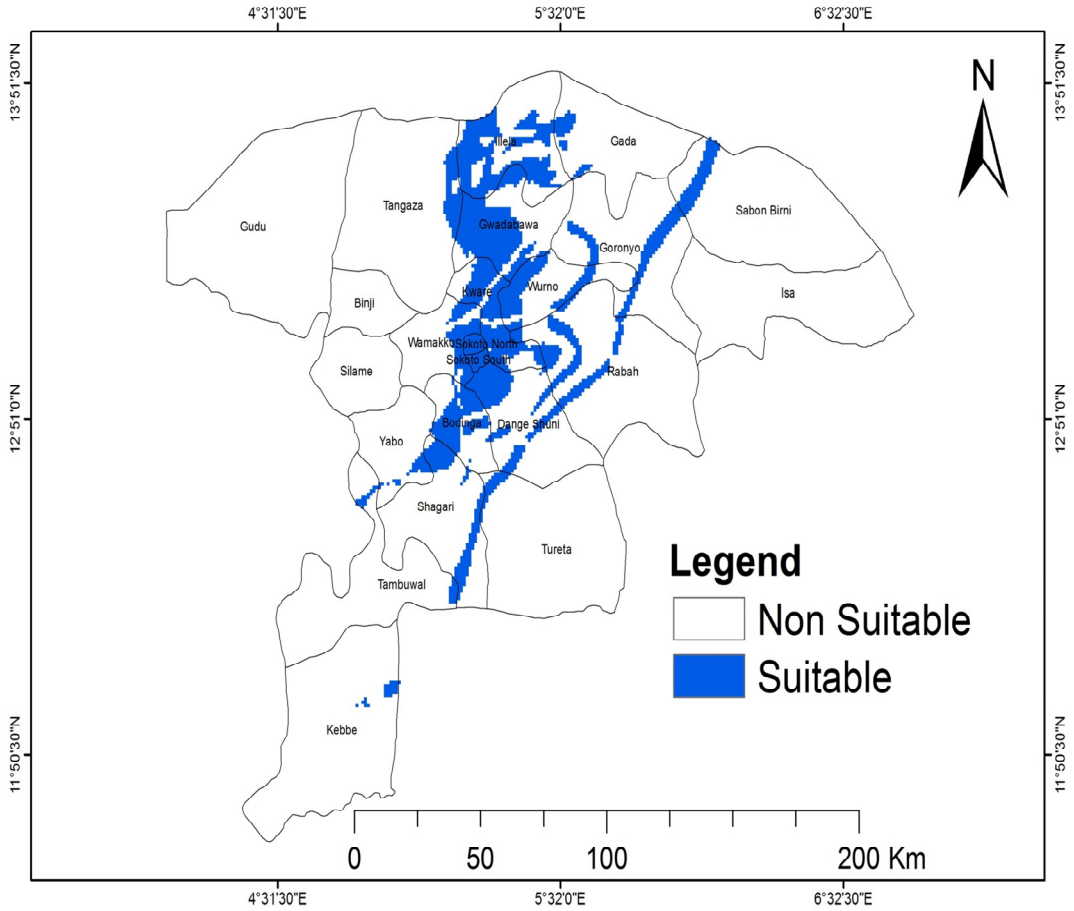

Figure 8: Phosphate suitability map for Sokoto State

Geochemistry

The interpretation of geochemical data indicates heterogeneous phosphate nodules (table 2). The P_2O_5 which represents the main components of phosphate ranges from 30.54-39.09% and averages 33.89%. This is very acceptable for raw rock phosphate.

Table 2: Geochemistry of Sokoto phosphate

Sample no	P_2O_5 (%)	CaO (%)	CaO/P_2O_5 (%)	F/P_2O_5 (%)	SiO_2 (%)	Al_2O_3 (%)	K_2O (%)	Fe_2O_3 (%)	MnO (%)
1	30.54	46.07	1.51	0.08	5.69	2.06	0.14	2.89	0.56
2	33.10	48.12	1.45	0.11	4.10	1.96	0.13	1.35	0.52
3	33.96	48.43	1.43	0.08	4.00	2.28	0.12	1.87	0.59
4	33.98	49.27	1.45	0.08	4.04	1.18	0.08	0.79	0.83
5	35.08	49.27	1.41	0.10	4.54	1.15	0.09	2.57	0.81
6	35.74	49.72	1.39	0.09	3.79	0.92	0.09	2.45	0.22
7	33.71	48.09	1.43	0.07	4.51	1.52	0.13	1.64	0.53
8	33.73	48.15	1.43	0.07	4.29	1.62	0.18	1.44	0.52
9	35.77	49.48	1.31	0.08	3.74	1.50	0.13	1.37	0.40
10	32.14	46.94	1.46	0.10	4.77	2.88	0.13	1.78	0.49
11	32.79	47.77	1.46	0.09	4.24	1.47	0.13	1.48	0.54
12	33.93	48.15	1.42	0.08	4.34	1.37	0.12	1.24	0.52
Average	**33.89**	48.35	1.43	0.08	4.32	1.64	0.12	1.71	0.47

Phosphate Rock

The phosphorites nodules of Sokoto State vary in colour from dark grey to pale yellow. They are also bioturbated with striations markings (figure 9).

Figure 9: Pale yellow and the dark grey variety of the Sokoto phosphates (photo: Author)

CONCLUSIONS

The final validation of study is based on the geospatial overlay of the sample area of study and the suitability map which gives a very good match (figure 10).

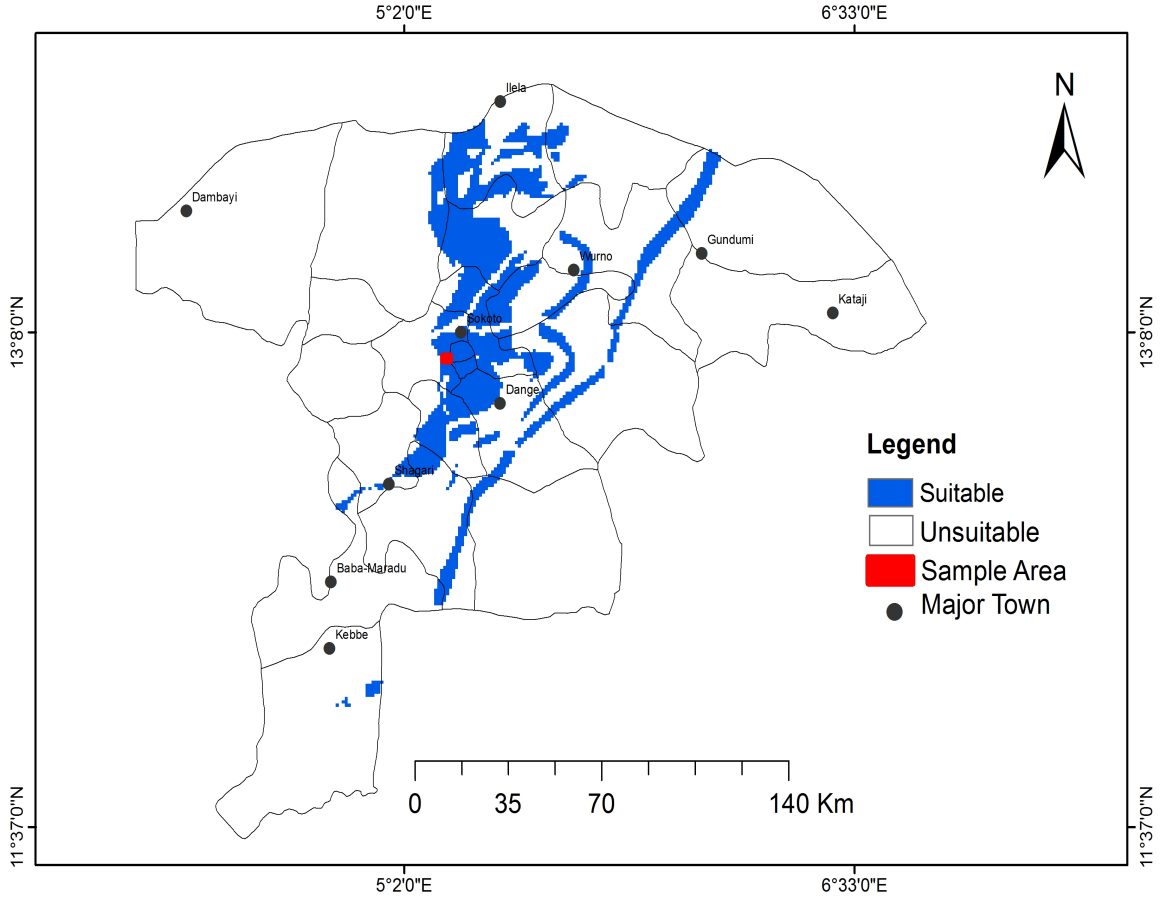

Fig 10: Validation of study map

Phosphate rock plays a vital role as an essential raw material in the manufacture of phosphate fertilizer, a use which account for nearly 90% of the world's output of phosphate rock. The trend towards trade in upgraded or beneficiated phosphate products rather than the raw materials itself has been a progressive one that will continue to shape the industry in the future. The factors that influence the phosphate rock world market include the P_2O_5 content, the effect of other chemical constituent among other factors.

The Sokoto phosphate can be beneficiated to 35% P_2O_5 which is a very acceptable grade for the manufacture of superphosphate fertilizers or the production of phosphoric acid for the manufacture of compound fertilizers. Phosphate rock imported to feed the Federal Superphosphate Fertilizer plant at Kaduna, Nigeria, from Togo was beneficiated to reach 34.88% P_2O_5 market grade (Okosun, 1997). Data from analysis indicate the Sokoto phosphate and the Togolese phosphate to be similar geochemically. They also have similar origin and process of formation. However, agronomic testing is important before application.

Study result indicates that, Gwadabawa, Dange, Wurno, Shagari, Wamakko, Sokoto North, Sokoto South, Kware, Bodinga and Illela LGA provides major sites for phosphates prospecting in Sokoto State, Nigeria and therefore very suitable.

Exploration and exploitation of this agro geological resource must be intensified as these will boost the growth of phosphate beneficiation plant in Nigeria and ultimately the manufacture of superphosphate fertilizer or phosphoric acid for the production of compound fertilizer. This will save national foreign exchange expended on the importation of rock phosphate

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