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INFLUENCE OF GEOLOGY ON SOIL PROPERTIES IN SOUTHERN ZONE, PLATEAU STATE, NORTH CENTRAL NIGERIA

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ABSTRACT:

The study is to ascertain the influence of various lithological units on soil properties in the southern zone of Plateau State. The area is underlain by the Precambrian basement rocks intruded by the Jurassic younger granites of varying textures. Intrusive volcanic rocks later intruded these rocks which directly overlies by the sedimentary rocks. These rock units weathered, leached and transported leading to the spatial variation of soil properties such as texture, pH, potassium and phosphorus. A total of 345 soil samples were collected using GPS, auger, and hand trowel. Stratified random sampling method was adopted for the field data collection. Soil samples were analyzed for their physicochemical properties. Also, spatial analysis (IDW) method was employed to ascertain the variation of the soil properties (pH, K, P, texture). Results showed pH, potassium and phosphorus are spatially distributed from very low to very high. Also, a comparative analysis of geology and soil texture showed that the spatial distributions of the soil texture were derived from the weathering of these rocks. The weathering of porphyritic biotite granite and medium grained biotite granite results in the coarse texture of the sandy, sandy clay and sandy loam soils. While the sedimentary rocks such as sandstone, alluvial sands and clays, limestone and shale influence the formation of sandy clay loam, sandy clay, sandy loam and silty clay in the area. Furthermore, results from analysis showed the spatial variation of potassium in the soils within the area is closely linked with the occurrence of orthoclase feldspars (K-Feldspars) in some crystalline rocks. Also, limestone, sandstones and shale could also be attributed to the variation of phosphorus content in the soil within the area. The occurrence of carbonate rocks such as limestone, shale and black shale in some parts of the area contributes to the relatively high pH within those areas. The occurrence of volcanic and intrusive crystalline rocks in the area contributed in generating acidic soils found in some areas. The study revealed the significant role of various rock units in the spatial variation of soil properties in the area.

Keywords — **Rock, Soil Properties, Potassium, Phosphorus, Spatial Variation**

I. INTRODUCTION

Soils provide the physical base for crop roots and are the principal source of nutrients. Soils are formed by a combination of the weathering of rock (source of the mineral components) and the decomposition of vegetation (source of the organic-matter components). The degree to which vegetation can thrive in a soil is determined by a variety of soil properties: depth, texture (grain-size distribution), organic-matter content, fertility (nutrient level), mineralogy, and degree of weathering. The role of geology is very significant in the spatial prediction of soil properties in the watershed of Lake Balaton, Hungary[1]. Soil properties such as fertility, pH, structure, texture and water-holding capacity has the global concern of today. In consonance, the geology (i.e. parent material) of any region attracts equal attention as does its resulting soil type. Analysis on the properties of soil, its cause and consequence on human livelihoods as well as on the environment is a matter of concern for sustainability, productivity and management of food. This important need has a huge local, regional, national and global consequent on food availability [2, 3].

Soil properties vary in spatial and temporal directions [4], and such variation depicts systematic changes as a function of the geology and derived landforms [5], 2002, soil parent material [6] and soil management practices[7].Although this concept remains viable, it is unfortunate to say that as much as soil-forming processes handle all spatial patterns, our knowledge of its determinants is inadequate [4, 8].This seems to be regrettably so because, several studies on soil properties centered on formation determinants like topography, climate and biota rather than on its parent-material(geology).Yet, the physical and chemical properties of soils are influenced by their parent-materials besides the influence of topography as reported by [9] and [10],

According to [11] the soils derived from basaltic rocks under tropical and sub-tropical environments, are reported to contain kaolinites and sesquoxieds as the major clay constituents and are variously classified as Oxisols, Ultisols and Alfisols (soil taxonomy). The major soil types of the southern zone of plateau state belong to broad category of tropical ferruginous soils which attain greater depths in the area. There are also sizeable pockets of clay soils and sandy-loam soils in this zone.

The main objectives of this study include; mapping out the various rock units, conduct soil properties analysis and ascertain the influence of rocks on these soil properties.

II. THE STUDY AREA

The study was carried out in the Southern Zone of Plateau State, which is a region comprising of six Local Government Areas in the state (Figure 1). These Local government areas are Langtang North, Wase, Mikang, Langtang South, Shendam and Qua'an Pan. The Zone covers a total land area of about 9,469km^2 and lies between latitude $8^0 36^{'} 89^{'}$ to $9^0 05^{'} 60^{''}$ N and longitude $9^0 09^{'} 41^{''}$ to $9^0 57^{'} 59^{''}$ E. It is bounded in the North by Kanke and Kanam LGAs, in the East and South by Taraba State, and in the West by Nassarawa State.

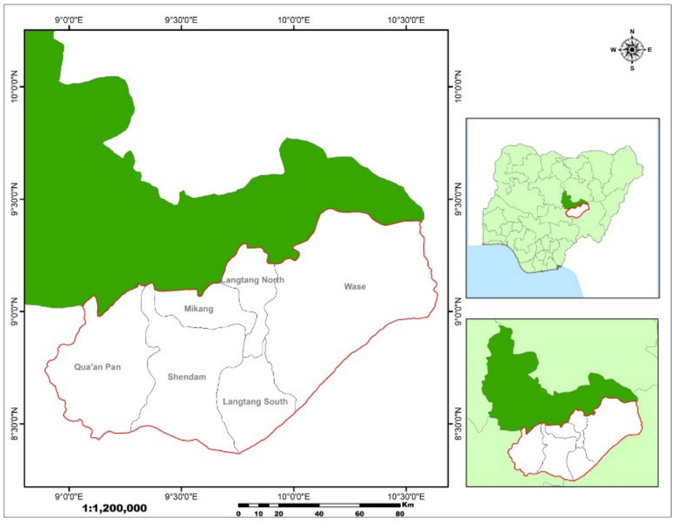

Fig. 1. The Study Area (Settlement map of Nigeria)

The area has a tropical savannah climate that is marked by two distinct seasons. The rainy season span from April to October and the dry Season is from November to March with a much colder period during the Harmattan (December to February). The yearly variation in wind speed ranges from 2.7 m/s to 3.6 m/s (weatherspark.com, 2023) with an average annual temperature range of 17^0C to 38^0. The average annual rainfall of about 131.75 cm (NIMET, 2018), humidity is highest around July and August, but its average annual is about 70%. The vegetation is typical of Guinea Savannah type and consists of short trees, long grass. There are occasional fringing woodlands (Gallery Forests) found along river banks, valleys, escarpments and steep margins of the highlands. The highland areas are mostly covered with Montane vegetation on mountain tops around hilly parts. These could be seen in the northern parts of Langtang North, Quanpan and Mikang.

The study area in part forms a fraction of the middle Benue trough. The topography of the Southern Zone of Plateau State is markedly different to that of the Jos Plateau. The Southern Zone has an undulating terrain and completely flat in most parts of Shendam, Wase and Langtang south; while Langtang North, Mikang and Qua'anpan Local government areas have undulating patterns with hills and mountains punctuating the plains. The Study Area can be categorized into high lands, which are to the north and west; and lowlands to the south and east. In the northern fringe of the area, where it meets the escarpment of the Jos Plateau (Upper Plateau), the land rises steadily. However, in the southern fringe, where it romances the banks of river Benue, the elevation is very low except for occasional isolated hills and knolls. The relief of the Southern Plateau can be viewed in two dimensions, that is, regions with elevations between 450m to above 1000m with respect to sea level, and regions with elevation below 300m above sea level. The Local Government Areas to the north and east of the study area; which are Langtang North, Mikang and Qua'anpan fall within the relief range of 450m to above 1000m, while regions in the south and west which include, Wase, Langtang south and Shendam falls within the relief range of below 300m above sea level.

A. The Drainage System

The area is bathed by many streams and rivers that flow southwards in a dendritic pattern which empty into the River Benue. Some of these rivers include River Wase, River Shimankar and River Dep. River Wase takes its source from the high land of Tafawa Balewa in Bauchi State and flows through Langtang North and Wase L.G.A.s to join River Benue. The major tributatries of River Wase are River Pilgani, River Bapkwai and River Zamko. Parts of Langtang North and Mikang LGAs have high relief (with the landscape rising from 200m to 1000m above sea level) particularly in the north and as such serve as hydrological centre for many small rivers that drains the area. River Shimankar is characterized by dendritic pattern and empties its water into River Benue. It takes its source from the Jibam Hills and flows southwards and empties into River Benue at Ibi in Taraba State. River Ankwa is an important landmark serving as a boundary between Plateau and Nassarawa States. It takes its source from the Jos Plateau and flows into the River Benue at Tunga in Nassarawa State. Therefore, the study area is well drained which leached most of these rock forming minerals and might be responsible for the spatially distribution of varying soil properties.

III. GEOLOGICAL SETTING OF THE AREA

The geology of the area falls within the Pre-Cambrian Basement migmatite-gneiss-quatrzite Complex, which underlies about half of the entire state. This complex has been, in some places, intruded by Pre-Cambrian to Late Paleozoic Pan-Africa Granite (Older Granite), diorite, charnockite, etc. The Jurassic anorogenic alkali Younger Granites intruded these basement complex rocks. In association with the Younger Granites are volcanic rocks such as basalts and rhyolites that overlay or cross-cut this formation as well as the basement rocks. These volcanic rocks are believed to have been formed during the Early Cenozoic (Tertiary), that is the ‘’Older Basalts’’; and during the Quaternary to form the ‘’Newer Basalts’’ [12]. The southern and eastern parts of the study area are overlain by Cretaceous and Tertiary to Recent sediments respectively (Figure 2). Langtang North is dominated by migmatite-gneiss and granite-gneiss (Basement rocks); biotite granite (Younger Granite); rhyolites and plugs of mafic rocks and pegmatite, all of which intruded into the basement unit which constitutes about 60% of the area[13]. While the migmatite-gneiss forms the lower plains underlying the entire area, the granite-gneiss, rhyolites and biotite granite form the higher grounds reaching heights of about 600m to 800m above sea level. There is no particular trend to show that they were biotite granite formed in the same way as that of the Jos Plateau (which are ring dykes) but occur as stocks. Situated between the granite-gneiss and migmatite-gneiss are massive bodies of rhyolite rocks trending in NE-SW direction. They are fine grained rocks with quartz and feldspar as the major minerals. They melted parts of the granite-gneiss as remnants of it were found in their matrix as xenoliths [14].

Mikang has a somewhat similar geology with Langtang North, except that it does not contain as much rock units as the latter. Thus, its underlain by migmatite-gneiss in the lower plains and by granite gneiss in the upper grounds. It also witnessed an intrusion of biotite granites and rhyolite in its higher grounds with intercalations of basalts and trachyte plugs to the western margin.

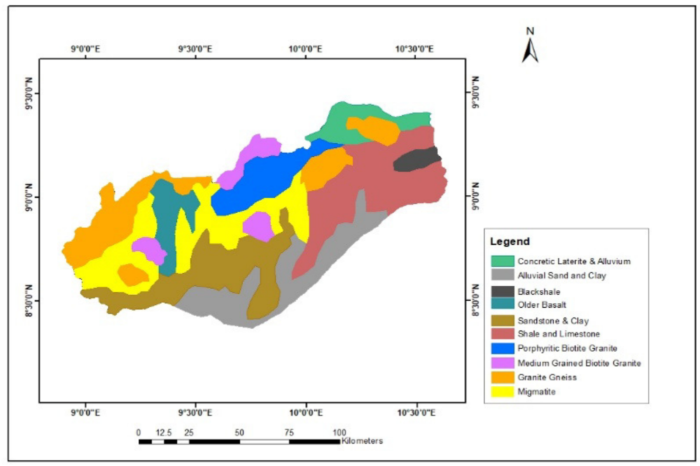

Fig. 2. Geology of the study area (Source: Nigerian Geological Survey Agency)

Wasefalls under sedimentary and basement terrain of Nigeria. The mapped geological units in this area include Mesozoic sedimentary rocks (sand stone and shale) of the Upper Benue Basin and hornblende biotite granite [15].Its record of volcanic activities is the land mark feature called the “Wase Rock”. This feature is a massive dome-shaped rocky inselberg found near Wase town in Wase L.G.A. Standing alone in the Wase plain, it achieves a remarkable height of about 298m (978 fts) above the surface of the neighboring surroundings and 543m (1781 fts) above sea level. It is a trachyte neck rising from the floor of the Benue Rift, 160km south-east of Jos. It is all that remains of a once giant volcano. It has been described as a volcanic plug and it is visible within a radius of about 40km due to its height. It is one of the five breeding places for the Rossy White Pelican birds in Africa. It’s now under government protection.

Mikang has a somewhat similar geology with Langtang North L.G.A., except that it does not contain as much rock units as the latter. Thus, its underlain by migmatite-gneiss in the lower plains and by granite gneiss in the upper grounds. It also witnessed an intrusion of biotite granites and rhyolite in its higher grounds with intercalations of basalts and trachyte plugs to the western margin.

Qua'an Pan lies within a mixed terrain of basement rocks (Older Granite and gneisses) and volcanic basaltic rocks [14]. Thus, the area is underlain by the Pre-Cambrian Basement Complex rocks of Nigeria which was intruded by the Newer Basalts of the Jos Plateau in the Cenozoic[16]. There are a few occurrences of pegmatite and basalts in form of boulders scattered on the surface.

On the other hand, Shendam is underlain by biotite granite which covers about 56% of the total area. Medium grained granite mostly outcrops on the central and south eastern parts and covers about 43% of the area. Syenite also occurs in the area and appears to have intruded into the biotite granite in the north eastern parts [17].

As for Langtang South, it is also underlain by the same crystalline basement rocks which are in turn overlain by Cretaceous sediments forming feldspathic and calcareous sandstone, shale and limestone intercalations, and sandy-clay and limestone [18].

IV. METHODS AND MATERIALS

A. Materials

The materials used are GPS, geological maps, desktop, ArcGIS 10.8 software, polythene bag, plastic bucket, masking tape, marker and auger. The research work is segmented into field work and data collection, detailed geological field mapping and laboratory analysis of soil samples. The field work was conducted for a period of 4 weeks which spanned from 3rdApril, 2021 to 4th May, 2021; GPS points of the soil samples were obtained using a handheld GARMIN GPSMAP 78s receiver. The different lithological units of the entire area were mapped during the geological field work. Soil samples were collected from selected farm locations using soil sampling auger at depths of 0–30cm. The samples collected were mixed thoroughly inside a plastic rubber to have one soil composite. The stratified random sampling method was adopted for the soil sampling based on the heterogeneity of the soils in the study region.A total of 345 soil samples were collected using GPS, auger, and hand trowel. The soil samples were analyzed for their physicochemical properties. Also, spatial analysis (IDW) method was employed to ascertain the variation of the soil properties (pH, K, P, texture). The laboratory analysis of the soil samples was conducted at Centre for Dry Land Agriculture, Bayero University, Kano, Nigeria. Total soil organic carbon (total C) was measured using a modified Walkley & Black chromic acid wet chemical oxidation and spectrophotometric method[19]. Total nitrogen (total N) was determined using a micro-Kjeldahl digestion method[20]. Soil pH in water (S/W ratio of 1:1) was measured using a glass electrode pH meter and the particle size distribution following the hydrometer method[21].Available phosphorus (avail. P), exchangeable cations (K, Ca, Mg and Na) and micronutrients (Zn, Fe, Cu, Mn, and B) were analyzed based on theMehlich-3 extraction procedure preceding inductively coupled plasma optical emission spectroscopy (MP-AES, 4200, Agilent Inc., Waltham, MA, USA). Exchangeable acidity (H + Al) was determined by extracting the soil with 1N KCl and titration of the supernatant with 0.5M NaOH[22]. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable cations (K, Ca, Mg and Na) and exchangeable acidity (H + Al).

The next phase of the study involved organizing and preparing the field data for spatial analysis. Initially, the collected field data's coordinates were carefully arranged within an excel worksheet and subsequently saved in the "CSV" format. To facilitate further spatial analysis, the data was imported into the ArcGIS 10.8 software for conversion into a shapefile format. This transformation allowed for more comprehensive and in-depth spatial analysis to be performed on the data.The main technique employed for spatial analysis was the Inverse Distance Weighted (IDW) interpolation extension in the Spatial Analyst tool of ArcGIS. This interpolation method is valuable for estimating values at unmeasured locations based on a set of known data points.

To build a relational database, the soil parameter values were imputed into the attribute table of the ArcGIS 10.8 software and linked accordingly. This database facilitated a comprehensive analysis of the spatial distribution of the physicochemical properties under investigation.The Inverse Distance Weighting interpolation method was particularly employed to delineate the spatial variation of the soil parameters across the study area. This approach allowed us to generate thematic maps representing the distribution of the chosen soil parameters.The point data obtained from the field were interpolated using the IDW technique.

B. Methods

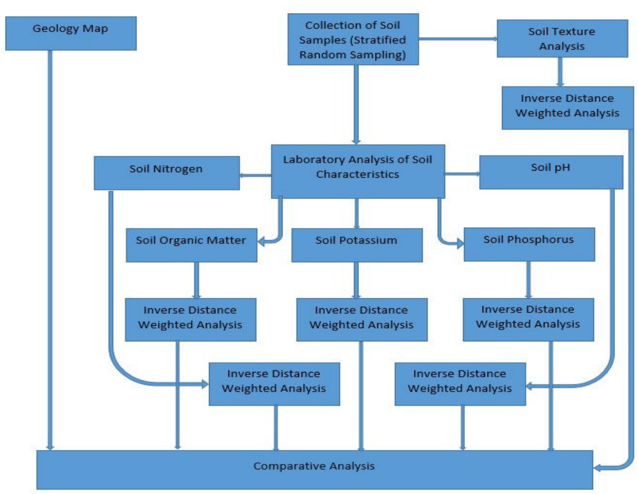

Fig. 3. Flowchart for the study

V. Results and Discussion

A. Soil texture

The results of this study revealed nine textural classes. The Inverse Distance Weighted (IDW) maps showed a wide textural variation of the soil. This ranges from sandy, sandy clay, sandy loam, sandy clay loam, clay, clay loam, loam, silty clay and silty clay loam. The spatial distribution map of the soil texture (Fig 5.) indicates that sandy clay loam soil was found in most parts of the study area covering 4681.8 km^2 (22.1%) of the total area mapped. On the other hand, silty clay loam covers the least area (317.1 km^2) which is less than 2% of the total area.

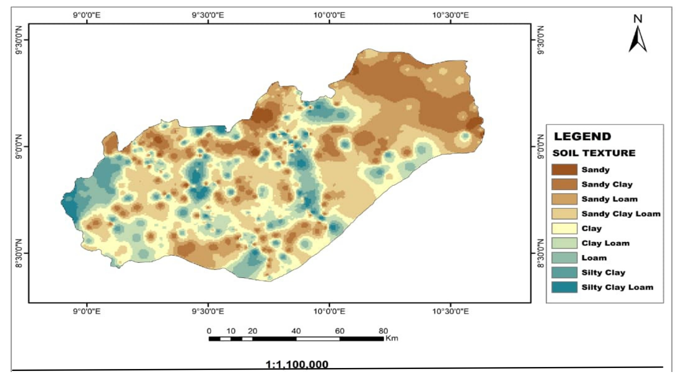

Fig 4. Soil texture

From the lithological units of the study area as presented in the geological map (Figure 2), the northern portion is dominated by crystalline basement rocks, mostly granite gneiss with migmatite and older basalt. Likewise, older granite rocks are also found within the area; mostly biotite granites of varying textures. The weathering products of these rocks are usually sandy (from the quartz components), clayey (as residue of feldspars) and sandy loam (from combined weathering of older granites and basement rocks. Furthermore, the textures of the parent rocks influence the soils generated from them. For instance, the rock types in and around Mikang L.G.A. are predominantly porphyritic biotite granite and medium grained biotite granite. This results in the coarse texture of the sandy, sandy clay and sandy loam soils that are found within these areas (Figure 2 and 4). The southern part of the study area contains several sedimentary rocks (such as sandstone, alluvial sands and clays, limestone and shale) which derive their texture from weathered materials from the central and northern parts of the study area. These soils are usually sandy clay loam, sandy clay, sandy loam and silty clay. Locations like Ajikamai in Shendam, Magama in Langtang South, Bakin Chiyawa in Qua'an Pan and Farin Ruwa in Wase, among others, illustrate these spatial relationships.

B. Spatial variation of soil pH

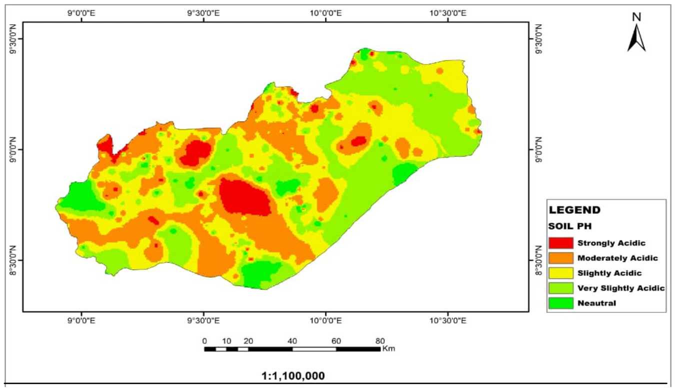

Fig. 5. Spatial variation of soil pH

The occurrence of carbonate rocks (limestone, shale and black shale) around Wase and environs with some sporadic distribution across parts of Langtang south, Shendam and Qua'an Pan contributes to the relatively high pH within those areas. The occurrence of volcanic and intrusive crystalline rocks around Mikang and Qua'an Pan contributes in generating acidic soils found in these areas. These volcanics often weather to form ferruginous soils. The effect of geology is quite evident in the north-western sector. Nevertheless, climate can also influence pH and sometimes overcome the effect of parent materials. This is quite evident on the Jos Plateau where rainfall is intense enough to leach the top soil, resulting in acidic soils. High acidity in the soil reduces most of the nutrient availability as well as directly affects root structure. The soils in the high altitudes and higher slopes had low pH values probably suggesting the leaching out of basic cations. Almost all the farming communities on the Plateau, especially where major crops such as yam, maize, Irish potatoes, rice, guinea corn and millet etc., are cultivated, experience continuous cultivation. This is as a result of growing population and the resultant land fragmentation. This continuous cultivation practices with excessive precipitation could also be some of the factors responsible for the reduction of pH in soils at the middle and upper elevation areas. In the study area, farmers have been continuously applying Urea and NPK (15:15:15, 20:10:10 etc.) as their main source of chemical fertilizers.

C. Spatial variation of Phosphorus

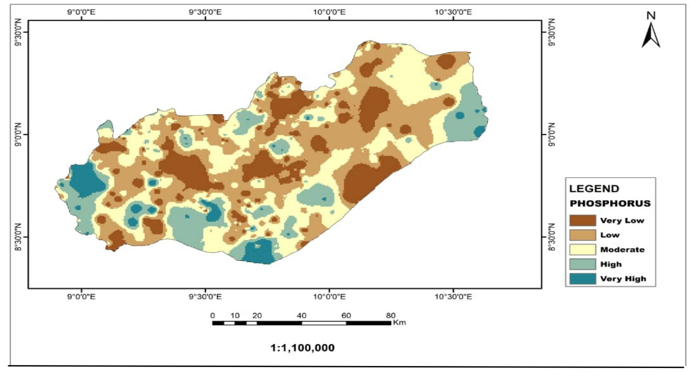

Fig. 6. Spatial variation of phosphorus

The primary source of phosphorus inputs in soils is from the application of chemical fertilizers and organic manure. The spatial distribution of phosphorus within the study area can partially be attributed to contents of phosphorus within the limestone, sandstones and shale in the southern part of the area (Figure 2 and 7). Portions of high and very high concentration at Pandam game reserves (Qua'an Pan) and the grazing reserve in Wase can be attributed to the presence of high organic matter arising from vegetation in the reserves and the product of waste foliage that decomposes to produce organic manure.

D. Spatial variation of potassium

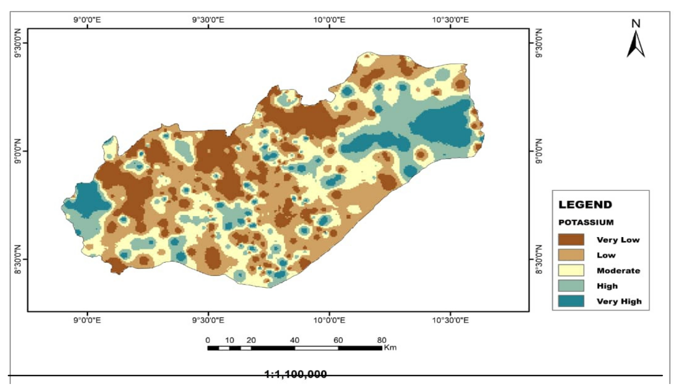

Fig. 7. Spatial variation of potassium

The spatial variation of potassium in the soils within the area is closely linked with the occurrence of Potassium feldspars (K-Feldspars) in some crystalline rocks. The dominant rock forming minerals in and around Mikang is biotite (Figure 2) which correlates with areas of noticeably low concentration (Figure 8). Consequently, several parts of the area record high to very high content of potassium. There is noticeable influence of crystalline parent rock material on these areas of high concentration particularly in areas with basalt occurrences. Orthoclase and plagioclase rich rocks have reasonable influence in the central belt of the area. Shale and limestone around parts of Wase could have some level of influence on the generally high to very high concentration of potassium. In tandem, bush burning activities may also contribute to concentrating potassium in this area. The periodic application of NPK fertilizers could also have some effect on the concentration of potassium.

CONCLUSION

The study clearly established the significant influence of the various lithological units on the soil properties. These rock outcrops (basement and sedimentary rocks) play vital role in soil formation and its texture. Also, the application of chemical fertilizers influences the spatial distribution of potassium, phosphorus and pH in the area.

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