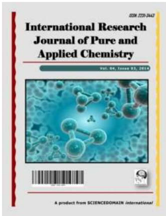

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Quality of Solid Minerals in Rocks and Soils of Mubi South Local Government Area of Adamawa State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author PA designed the study, wrote the protocol, managed the literature search and wrote the first draft of the manuscript. Authors PA and HMM preformed the statistical analysis and carried out some aspects of the experimental work. Authors PA, HMM and JTB managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Nigeria is richly endowed with huge solid mineral deposits; there is need therefore, to identify the different types of solid minerals in rock and soil of Mandara Mountains in Mubi region and also to assess their quality by determining their elemental compositions. The quality of solid minerals in soils and rocks of Mubi South local government area of Adamawa state in Nigeria was studied. Thirty samples, fifteen each of soil and granite rocks were collected from the sampling areas and the elemental composition was determined using the X–Ray Fluorescence (XRF) Spectroscopy (Axios cement Pan Analytical model), while the mineral identification was done using X- Ray Diffraction (Rayon's model). The results of the chemical analysis showed that all the areas sampled

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contained silicate rocks, because of their high silica contents ranging from 69.23±1.00% to 75.57±1.02% and 60.65±1.00% to 68.20±0.80% in granite rock and soil samples respectively. However, the result from XRD indicated high percentage of quartz, feldspar and other minerals as microcline, albite and orthopyroxene Crystallographic parameters of all the identified minerals are hexagonal, anorthic, orthorhombic and rhombohedral. Most of the soil samples contained higher percentage of Al_2O_3, K_2O and Fe_2O_3 than the rock samples, while the rock samples showed higher percentage of SiO_2 and Na_2O than the soil samples, the comparative analysis between rocks of this area and similar rocks elsewhere, showed that, they competes favourably with respect to their chemical compositions. Based on the analysis, the principal rocks commonly found in the study area are granite and rhyolite.

Keywords: Quality; solid mineral; rock; soil; Mubi South; Adamawa state.

1. INTRODUCTION

As a result of the need for technological advancement, the modern world cannot proceed meaningfully without solid mineral resources [1]. Industrial advancement cannot be enhanced without the availability of solid minerals. Most important products of solid minerals from the earths crust are gold, copper, zinc, lead, iron, aluminum, mercury, platinum, and silicon among others [2]. The rare earth elements like uranium, plutonium and thorium are used in nuclear reactors and war heads [1]. Rock products such as granites and limestone constitute minerals and are used for infrastructural development. All minerals are distributed in different levels and at different locations in rocks in the world [3].

Nigeria as a nation is blessed with abundant solid minerals resource distributed fairly across her states. According to reports by the Nigerian Geological Survey Agency, Nigeria has some 34 known major mineral resources deposit distributed in locations across the country. Exploration in Nigeria for solid minerals such as Tin, Niobium, Lead, Zinc, and Gold goes back for more than 90 years and the exploration of marble, feldspar and Cold started in the 1970's [4].

The knowledge of major and trace elemental abundances in various rock samples is of vital importance to the study of specific types of minerals and chemical composition of rocks [5]. There are specific elements or combination of elements which are known to be associated with specific types of minerals; therefore, it is possible to evaluate the potential for existence of certain types of minerals by evaluating which elements are found in a given area [6].

It is suggested that Nigeria's relatively low industrial minerals production from the basement rocks is as a result of lack of comprehensive and reliable data about these deposits. Also, depending on oil as its main source of revenue, solid mineral sector which can complement revenue generation has been neglected. In order to provide comprehensive and reliable data on industrial minerals potential of parts of the country, the Mubi region feldspar mineral deposits hosted by granites and pegmatites was chosen for this study.

Apart from containing rare earth elements and gemstones such as tourmaline, tantalite, topaz and aquamarine, pegmatites usually contain crystals of quartz, feldspar and mica in quantities of economic value. The feldspar, quartz and mica usually occur in different varieties and with different physical and chemical properties suitable for different industrial purposes [7]. This work therefore evaluates the feldspars, quartz and related minerals associated with the granitic and pegmatitic intrusive rocks of Mubi region in order to classify and quantify them and to decide whether the data produced from the study justify any investment in the deposits.

The Nigerian basement complex rocks of northeastern Nigeria (Mubi region in particular) are the least studied and as a consequence very little discoveries of economic mineral deposits are made. Most of the minerals being exploited are industrial which include feldspar, quartz, clays and some gem minerals. Within the study area only feldspar and quartz are being mined although occurrences of some other minerals have been reported. Baba [8] reported the occurrence of sulphides as disseminations within the Older Granites of Mandara Mountains. Abaa and Najime [3] suggested that exploration in the N-S Oban-Obudu- Mandara-Gwoza axis be concentrated at places where the basement rocks have been metasomatized by the later volcanic dykes, pegmatite and quartz veins. It has been observed that topaz, sapphire, beryl and fluorite are some of the main minerals produced by metasomatism of the basement rocks by the Tertiary volcanic activities. Dada [9] reported that of the Pan-African granitoids, only the late to post tectonic phases such as pegmatities, quartz vein, micrograntes and basic ultrabasic intrusive have indicated substantial mineralization potentials, particularly as sources of sulphides, chrome, nickel ores and kimberlited. The quality of solid minerals from this study was assessed, by determining the concentrations of the mineral oxides and comparative studies of the results and similar results elsewhere.

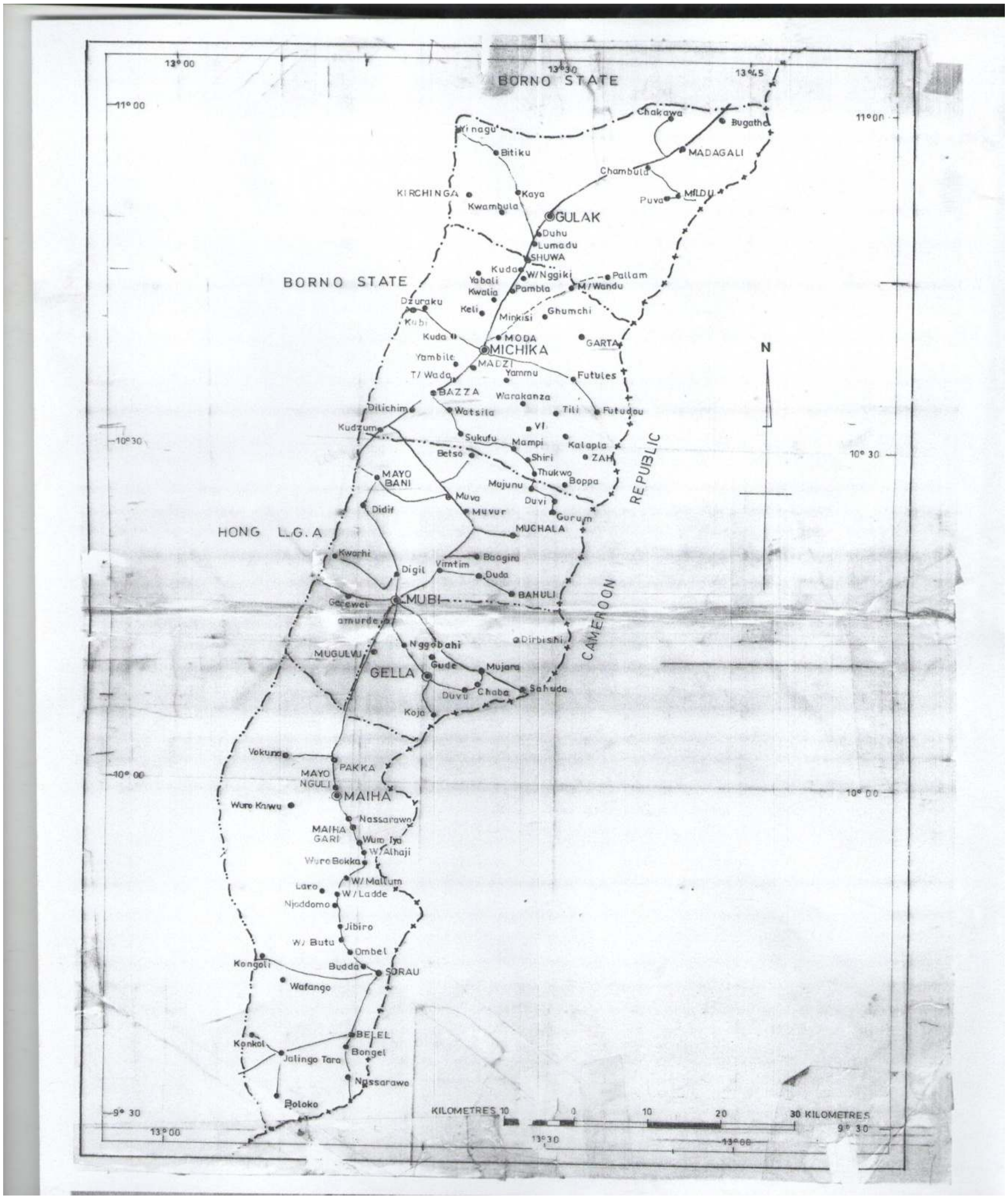

Fig. 1. Map of Mubi region showing the sampling locations

2. MATERIALS AND METHODS

2.1 Study Area

The study area (Mubi region) is situated in the north-eastern part of Nigeria, in the northern part of old Sardauna Province which now forms Adamawa northern senatorial district as defined by INEC (1996) [10,11]. The region lies between latitude 9°30 ^{1}N and 11°14 ^{1} N and longitude 13° and 13°45 ^{l} E. Mubi region is bounded in the north by Gwoza local government area of Borno State, in the west by Hong and Song local government areas and in the south and east by the Republic of Cameroon. It has a land area of 4728.77 KM2.

The region consists of five local government areas namely Madagali, Maiha, Michika, Mubi North and Mubi South [11]. Mubi region is located within the North East Basement complex of Nigeria. The rocks are pre pan African orogenic rocks (gneiss migmatite rocks) or pan African granitoids (older granites). They geological structures predominant in the area are dykes, quartz, veins, folds, sheer zones [12].

The gneisses and migmatites occupy mainly the lowlands as small outcrops. They are bended, foliated with felsic and for ferromagnesian minerals forming the light and dark bands respectively. This mineral differentiation imparts the foliation to the rocks. The granitoids which are younger are intrusive to the gneissic and migmatic rocks [12].

Investigation into the Mubi region area reveals an area having high potential to host economic deposits of feldspar, quartz, tourmaline and tantalite. The mineral commodities are found in three modes of occurrence, each of which contains two or more of the economic minerals.

1) The unweathered granitic rock is favourable for the occurrence of primary deposit of sodium feldspar, potassium feldspar and quartz.
2) The unweathered pegmatites that intrude the granitic and schistose rocks of the study areas are the most favourable for the occurrence of these economic minerals.
3) The weathered granitic and pegmatitic rocks are favourable for residual deposit of clay that contains feldspar, quartz, tourmaline and tantalite [13].

2.2 Sample Collection and Treatment

Granites rock and soil samples, mostly loamy soils were collected from Sahuda, Duvu, Mondova, Gella and Mujara in Mubi South Local government area.

Soil types were sampled using Dutch soil auger to collect core samples at 0 to 50 cm soil depths. Ten core samples from each sampling location were randomly collected and mixed properly to give a composite sample mixture. The homogenized composite samples were air-dried, crushed and sieved using 2 mm sieve. The less-than-2 mm fraction of each sample was kept in a polythene bag and labeled [14,15].

Table 1. Sampling sites and locations

Locations	Sites	Samples	Remark
Sahuda	Sahuda	1	Rock and soil
	Sahuda	2	Rock and soil
	Sahuda	3	Rock and soil
Duvu	Duvu	1	Rock and soil
	Duvu	2	Rock and soil
	Duvu	3	Rock and soil
Mondova	Mondova	1	Rock and soil
	Mondova	2	Rock and soil
	Mondova	3	Rock and soil
Gella	Gella	1	Rock and soil
	Gella	2	Rock and soil
	Gella	3	Rock and soil
Mujara	Mujara	1	Rock and soil
	Mujara	2	Rock and soil
	Mujare	3	Rock and soil

Rock samples were collected from each sampling location, broken into manageable sizes for easy transportation to the laboratory. The collected rock samples were stored in labeled sample bags. Each of the rock samples collected was air-dried in the oven at 30℃ to a constant weight and crushed with a jaw crusher, and ground in a vertical pulverized Simatic C7-621 model into fine powder.

2.2.1 Sample preparation for XRF and XRD analsis

The pulverized samples of the solid minerals (rock and soil) were passed through 355 um sieve size and 0.3 g was homogenized with 3mg of polystyrene dissolved in toluene serving as a binder.

The pellets were formed by pressing at 10 tons with hydraulic press to form a pellet of about 19mm. The pellets were subjected for X-ray dispersive spectroscopy with specific emission properties reported by authors [16-18].

X-ray Diffraction analysis was used as the major tool for identification of phases and minerals [19].

2.3 Statistical Analysis

All analysis was performed in triplicates. Results are in the form of means ± SD. Statistical significance was established using one way Analysis of Variance (ANOVA). Means were separated according to Duncan's multiple range analysis ($p<0.05$).

3. RESULTS AND DISCUSSION

The results of the percentage mineral oxides compositions of solid minerals in soil and rock samples of Mubi South local government area of Adamawa state are presented separately in Tables 2, 3 and 4 respectively. Figs. 2 and 3 showed the comparison of mineral oxides compositions for the different locations in rock and soil. The minerals as identified by XRD analysis are seen in Figs. 4 and 5 respectively.

The results of mineral oxides concentrations in rock and soil samples were as shown in Tables 2 and 3. The qualitative analysis revealed that the average SiO_2 contents varies from 69.23±1.00% to 75.57±1.02% and 60.65±1.00% to 68.20±0.80% for the study in soil and rock samples respectively. The highest mean concentration (75.57±1.02%) in rock was recorded in Sahuda and the highest concentration (68.20±0.80%) in soil was registered in Mondova. This investigation confirmed that the rock of the study area have higher percentage of SiO_2 than the soil. The presence of high percentage of silicates in rock and soil reveals that, most of the rock and soil are rock forming minerals, which consists of quartz, potassium feldspar, sodium and calcium plagioclase (feldspars), which commonly contains such accessory minerals as biotite, orthoclase, microcline, hornblende, muscovite and pyroxene. Garba [20] reported that most of the minerals being exploited in the basement complex rocks of northeastern Nigeria are industrial which include feldspar, quartz, clay and some gem minerals.

The average Al_2O_3 content ranged from 11.80±0.70% to 14.26±1.03% in rock and 16.06±0.70% to 21.78±0.70% in soil. The highest mean concentrations (14.26±1.03%) in rock and (21.78±0.70%) in soil are found in Duvu and Mujara respectively. The value in soil is high compared with many other studies [7,8]. The chemical analysis showed that Mujara soil contained higher percentage of Al_2O_3 as compared with the rock of the study area. The mineral oxides compositions average Fe_2O_3 contents of granite rock and soil ranged between 1.02±0.70% to 5.75±0.90% and 3.91±0.98% to 7.61±1.02% respectively. The highest concentrations in rock (5.75±0.90%) and in soil (7.61±1.02%) are recorded in Duvu. The analysis revealed that Duvu and Mujara soils contained higher percentage of Fe_2O_3, (7.61±1.02% and 7.55±0.76% respectively) showing that the two locations are enriched in their Fe_2O_3 contents. This concentration was not surprising because of the relative abundance of Fe in the earth crust and in solid mineral like tantalite and columbite, Fe is one of the major compositions of these solid minerals [17] reported about the %Fe_2O_3 (7.87) in tantalite samples of Maikabanji indicating the presence of ilmenite in the sample. This is also because the deep chemical weathering of rock in hot, humid, tropical climates promotes mineral enrichment, and also the solution and removal of more soluble materials leaves a residual of less- soluble minerals. Iron and aluminum are relatively insoluble under this condition, they tend to remain behind in laterite, a highly weathered, red sub-soil or material that is rich in oxides of iron and aluminum and lacking in silicates [21].

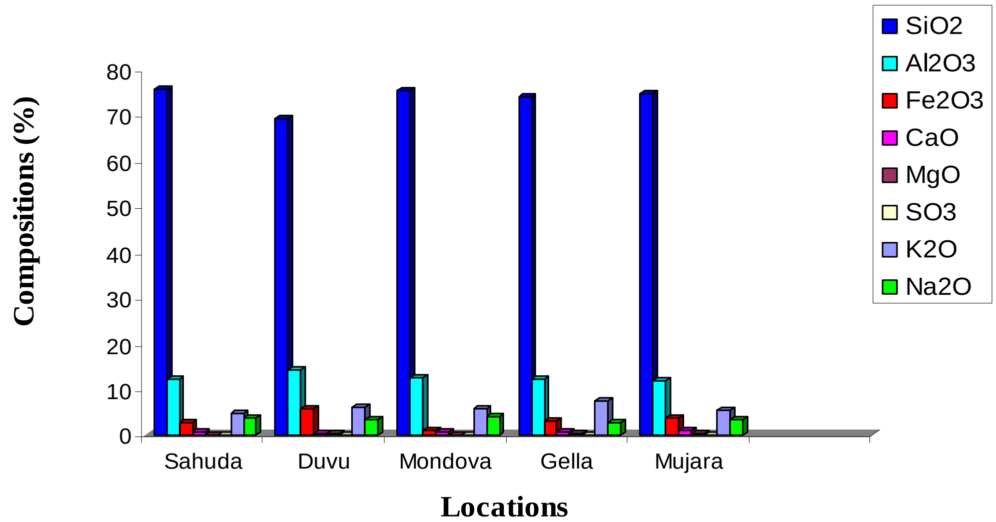

Fig. 2. Comparison of major components for the different locations in rock

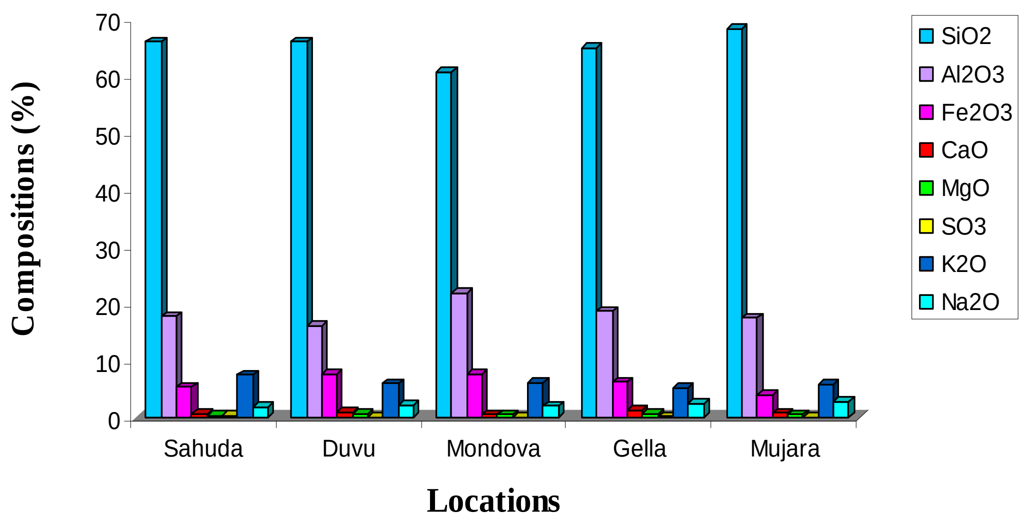

Fig. 3. Comparison of major components for the different locations in soil

The average K_2O content varies between 4.88±1.02% to 7.39±0.98% and 5.20±0.90% to 7.34±0.50% in rock and soil samples respectively. The highest average values (7.34±0.50%) in soil and (7.39±0.98%) in rock are found in Sahuda and Gella respectively. The Mubi area is part of the basement complex of Nigeria and is underlain mainly by schists and intrusive granitic and pegmatic rocks along with a significant K_2O component (k-feldspar). A study of the area reveals the occurrence of feldspar deposit hosted by granitic and pegmatitic intrusive. The average concentrations of CaO, MgO, SO_3, and Na_2O from all the sampling locations in the rock and soil of the study area are comparable from one sampling point to another as shown in Fig. 2 and Fig. 3.

The L.O.I (Loss on ignition) varies from 0.63 to 1.42 in rock and 0.72 to 1.75 in soil. The highest value (1.42%) in granite rock and (1.75%) soil samples are recorded in Sahuda and Duvu respectively. The result revealed low concentrations of loss on ignition in all the study area. This indicated that the minerals do not contain decomposable matter such as carbonate.

Table 2. Mineral oxides compositions of soils samples (%)

Locations	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**L.O.I**
Sahuda	65.93±1.00	17.70±0.85	5.38±1.03	0.61±0.50	0. 24±0.60	0.13±0.30	7.34±0.50	1.76±0.30	0.72
Duvu	65.87±0.98	16.06±0.70	7.61±1.02	0.94±0.40	0.60±1.00	0.06±0.20	5.96±0.60	2.17±0.20	1.75
Mondova	68.20±0.80	17.35±0.60	3.91±0.98	0.81±0.60	0 .37±0.90	0.05±0.30	5.74±0.80	2.66±0.30	1.08
Gella	64.85±0.98	18.71±0.90	6.15±0.88	1.20±0.80	0.6 2±0.80	0.07±0.40	5.20±0.90	2.37±0.40	1.62
Mujara	60.65±1.00	21.78±0.70	7.55±0.76	0.49±0.61	0.53±0.70	0.03±0.30	5.99±0.90	1.96±0.40	0.97
Range	60.65±1.00 68.20±0.80	16.06±0.70 21.78±0.70	3.91±0.98 7.61±1.02	0.61±0.50 1.20±0.80	0.24±0.60 0.62±0.80	0.03±0.30 0.13±0.30	5.20±0.90 7.34±0.50	1.76±0.30 2.66±0.30	0.72- 1.75

(±) values are the Standard deviation of three replicate analyses

Table 3. Mineral oxide compositions of rock samples (%)

Locations	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**L.O.I**
Sahuda	75.57±1.02	12.07±0.99	2.62±0.80	0.52±0.03	0. 04±0.02	0.03±0.80	4.88±1.02	3.57±1.00	1.42
Duvu	69.23±1.00	14.26±1.03	5.75±0.90	0.43±0.40	0.38±0.20	0.01±0.70	6.14±1.04	3.51±1.00	0.63
Mondova	75.28±0.98	12.41±0.89	1.02±0.70	0.55±0.30	0.08±0.30	0.02±0.30	5.75±1.03	4.02±0.80	0.66
Gella	73.86±0.90	12.07±1.00	3.07±0.90	0.71±0.40	0.2 4±0.30	0.01±0.50	7.39±0.98	2.71±0.90	0.93
Mujara	74.45±1.01	11.80±0.70	3.72±0.80	0.87±0.80	0.18±0.40	0.02±0.60	5.56±0.80	3.34±1.02	0.72
Range	69.23±1.00- 75.57±1.02	11.80±0.70- 14.26±1.03	1.02±0.70- 5.75±0.90	0.43±0.40 0.87±0.80	0.04±0.02- 0.38±0.20	0.01±0.70- 0.03±0.80	4.88±1.02- 7.39±0.98	2.71±0.90- 3.57±1.00	0.63- 1.42

(±) values are the Standard deviation of three replicate analyses

Table 4. Comparative analyses between Granitic Rocks from Sahuda, Duvu, Mondova, Gella, Mujara of Mubi South sampled area and similar rocks elsewhere

Elements	A	B	C	D	E	F	G	H	I	J	K	L	M	N
SiO_2	75.57	69.23	75.28	73.86	74.45	69.69	72.20	77.76	68.77	73.66	69.20	63.31	69.67	72.04
Al_2O_3	12.07	14.26	12.41	12.07	11.80	13.99	13.70	12.60	13.75	14.35	14.86	15.12	15.17	14.42
Fe_2O_3	2.62	5.75	1.02	3.07	3.72	3.26	1.85	0.44	5.18	0.94	3.11	2.00	1.34	1.22
CaO	0.52	0.43	0.55	0.71	0.87	1.96	1.40	0.45	2.45	1.32	1.89	3.88	1.71	1.82
MgO	0.04	0.38	0.08	0.24	0.18	1.40	0.38	0.05	0.41	0.11	0.60	1.56	0.04	0.71
SO_3	0.03	0.01	0.02	0.01	0.02	-	-	-	-	-	-	-	-	-
K_2O	4.88	6.14	5.75	7.39	5.56	4.12	5.04	3.33	4.28	4.11	5.17	4.10	2.28	4.12
Na_2O	3.57	3.51	4.02	2.71	3.34	3.48	3.53	3.70	3.33	3.53	3.64	2.93	2.56	3.69
L.O.I	1.42	0.63	0.66	0.93	0.72	0.97	-	1.22	0.60	0.65	-	0.04	-	-

Key: A= Sahuda, B = Duvu, C = Mondova, D = Gella, E = Mujara,(this work) F = Madagali granite [22]. G = Average granite from Lokoja [23], H = Granite from Gumchi area Madagali [24], I = Granites from Toro Charnockitic Complex (TCC) NE, Nigeria [25], J = Anatectic Granites from northern Cameroon [26, K= average of older granites from Saminaka and Ririrwai, N. Nigeria [27], L = Jato Aka Monzogranits from SE Nigeria [28], M= Igbeti coarse porphyritic granites from SW Nigeria [29], N = World wide average proportion of different chemical components in granite based on 2485 analyses [30].

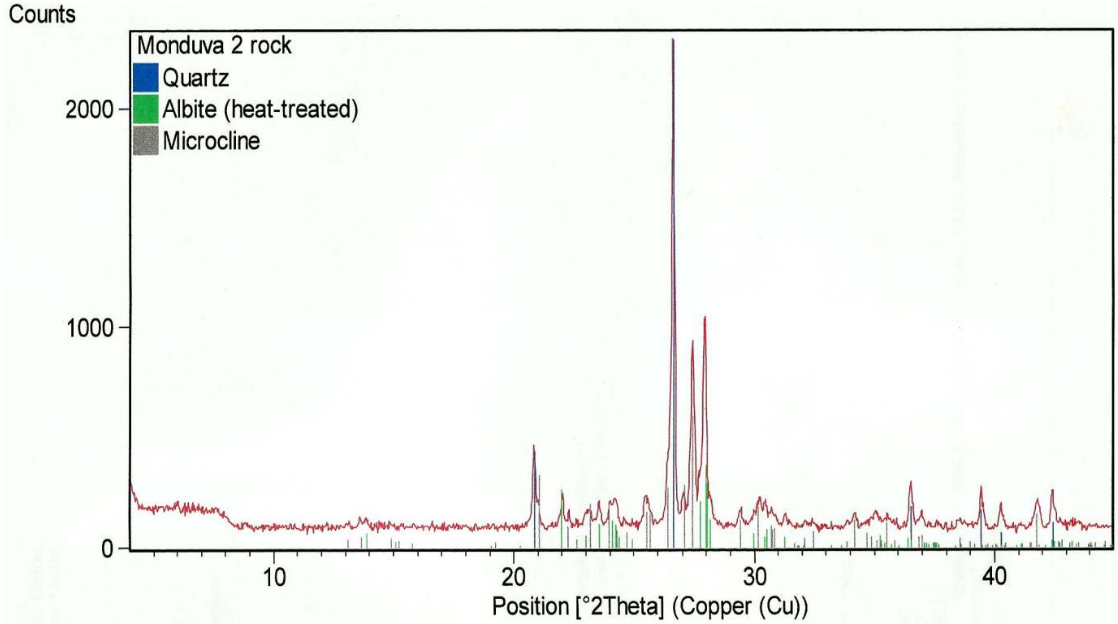

Fig. 4. Major minerals as identified by X-Ray diffraction spectrophotometer in rock

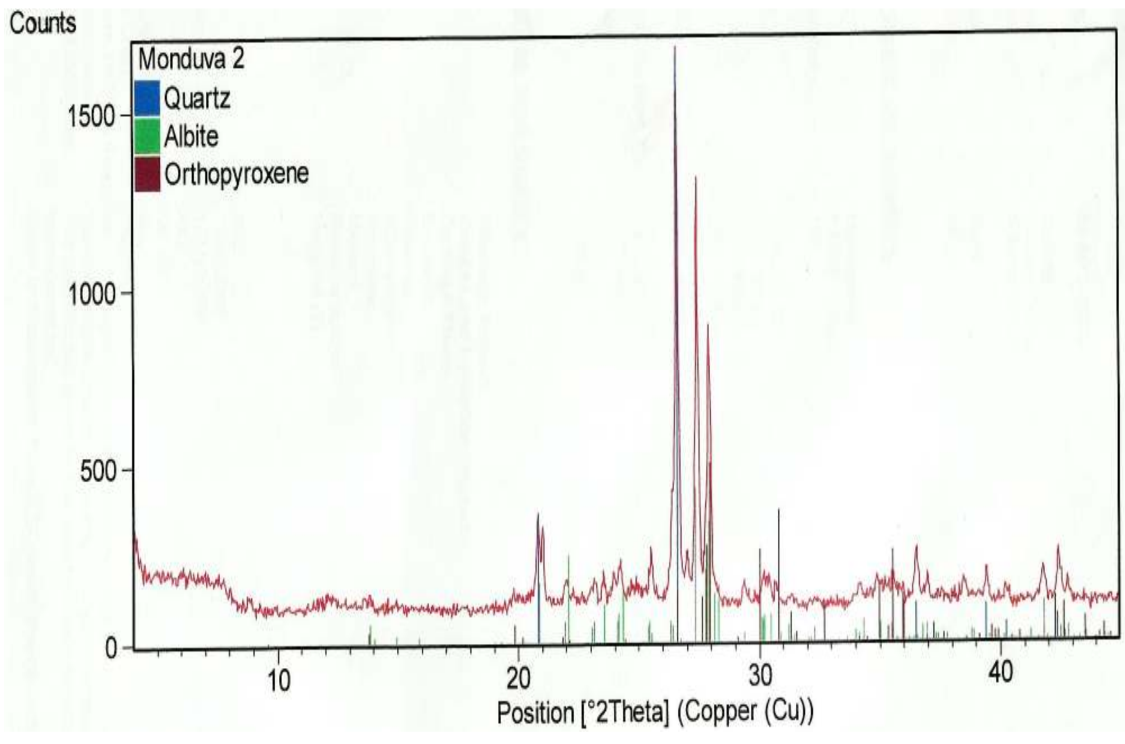

Fig. 5. Major minerals as identified by X-Ray diffraction spectrophotometer in soil

When compared with similar granitic rocks from other places, (Table 4) it is observed that the studied granitoids on average are enriched in SiO_2, Sahuda (75.57%), Mondova (75.28%), Gella (73.86%) and Mujara (74.45%), which compares favourably with the average granite from Lokoja [23] (72.20%), anatectic granites from northern Cameroon [26] (73.66%) and

Granite from Gumchi area Madagili [24] (77.76%) and also they relate favourably with respect to Al_2O_3, CaO, MgO, and Na_2O (A, C, D, E and H, Table 4). The Duvu granitoids are comparable in many respects to the granites from Toro Charnockitic complex (TCC) NE, Nigeria [25], Madagali granite [22] and older granites from Saminaka and Ririrwai, N. Nigeria [27] with respect to SiO_2, Al_2O_3, Fe_2O_3 and K_2O, (B, F, I, and K Table 4). The Jato Aka Monzogranites from SE Nigeria [28] and Igbeti coarse porphyritic granites from SW Nigeria [29] (L and M Table 4) are enriched in Al_2O_3 and CaO but impoverished in SiO_2 and Fe_2O_3 as compared to the granites of the study area. The result obtained from the chemical analysis of granite rock samples from Sahuda, Duvu, Mondova, Gella and Mujara (Table 2), are comparable with worldwide average proportion of different chemical components in granite based on 2485 analyses [30] (N, Table 4).

The X-ray diffractometer (XRD) pattern for the rock sample is as shown in Fig. 3. The qualitative analysis revealed that the sample constituents include Silicon oxide, Sodium Aluminum Silicate and Potassium Aluminum Silicate with hexagonal, rhombohedra, orthorhombic and anorthic crystal structure lattice system respectively. The XRD pattern for soil sample is shown in Fig. 4, consisting of Silicon Oxide, Aluminum Phosphorus Oxide, Sodium Aluminum Silicate, Iron Magnesium Silicate, Potassium Aluminum Silicate with Hexagonal, Anorthic, Rhombohedral and Orthorhombic crystal structure respectively. It was observed that all the samples consist of silicon oxide, Sodium Aluminum Silicate and Potassium Aluminum Silicate. In addition to this, silicate and aluminum are the major elements present in the rock and soil samples.

From the XRD result the most common and abundant minerals found in the study area are quartz and feldspars which occur as albite, orthopyroxene and microcline. Figs. 3 and fig. 4 also showed the various peaks heights of the different minerals identified in rock and soil samples of the various locations. Fig. 6 shows the comparison of the silica and alumina ratio, this compliment the XRD results to ascertain the types of silicate the rocks constitute of.

The relative abundance of silica compared to the sum of alumina and iron oxide is

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} = SR$$

Where, SR refers to silica ratio. Silica ratio, to observe the variations of silica compared to Al and Fe.

The abundance of aluminum compared to iron can also be expressed as,

$$\frac{Al_2O_3}{Fe_2O_3} = AR$$

Where, AR refers to alumina ratio. Alumina ratio gives the variation of Al and Fe.

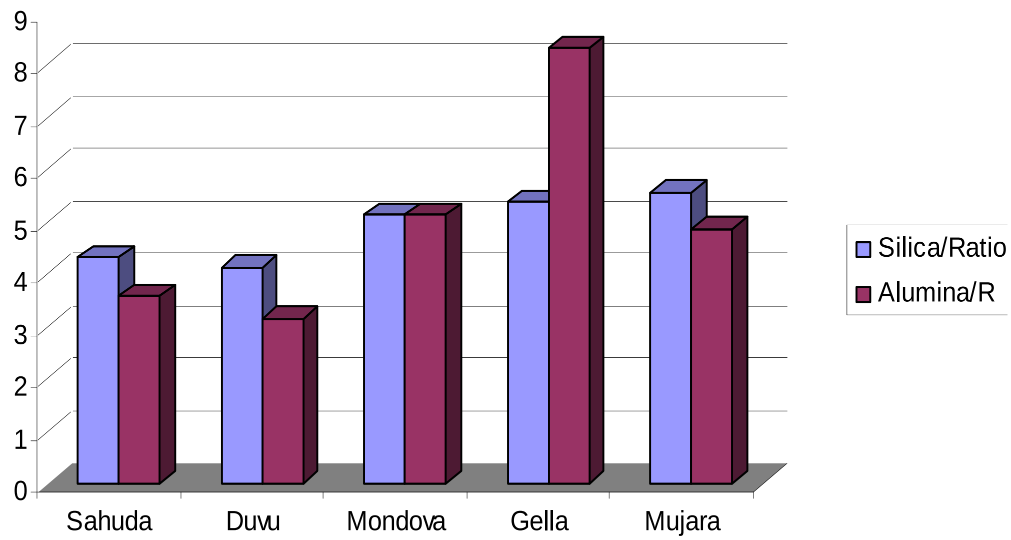

Fig. 6. Comparison of the silica and alumina ratio of rocks

4. CONCLUSION

From the results of the chemical analysis of samples, one can conclude as follows.

The minerals identified in granite rock and soil samples in different locations in the region are quartz and feldspar, which are the most abundant minerals, occurring as albite, microcline and orthopyroxene. Fig. 6 shows the comparison of the silica and alumina ratio, this compliment the XRD results to ascertain the types of silicate the rocks constitute of. The results of granitic rock and soil samples contained SiO_2 as the most abundant mineral oxide in all the areas studied followed by Al_2O_3, K_2O, Fe_2O_3, and Na_2O in decreasing order of percent composition.

The results of mineral oxides components of rocks compare favourably with those of soil samples in each of the locations. Crystallographic parameters of all the identified minerals are hexagonal, anorthic, orthorhombic and rhombohedral.

The region studied has mineral components similar to other granitic rocks elsewhere in Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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