Eurasian Journal of Science and Technology

2023, Volume 3, Issue 4

Original Article

Chemical Profiling of Minerals and Elemental Composition of Rock and Soil Samples from Bakin Dutse Hills, Madagali, Adamawa State Nigeria

Aliyu Benson| Ayodele Akinterinwa* | Charles Milam | Abdulazeez M. Hammed

Department of Chemistry, Modibbo Adama University Yola, Nigeria

Use your device to scan and read the article online

Citation A. Benson, A. Akinterinwa, C. Milam, A. M. Hammed, **Chemical Profiling of Minerals and Elemental Composition of Rock and Soil Samples from Bakin Dutse Hills, Madagali, Adamawa State Nigeria.** *Eurasian J. Sci. Technol.,* **2023**, *3*(4), 232-245.

https://doi.org/10.48309/ejst.2023.416370.1090

Article info:
Received: 2023-09-14
Accepted: 2023-10-13
Available Online: 2023-10-27
ID: EJST-2309-1090
Checked for Plagiarism: Yes
Checked Language: Yes

Keywords:
Rocks; Minerals, Elemental Deposits, X-ray Diffraction (XRD), X-ray Fluorescence (XRF).

ABSTRACT

Evaluation of natural resources via chemical profiling is a prerequisite to mining and material sourcing, which are important activities in positioning an economy for the future. This study explores the untapped rocks located within the Bakin Dutse hills in Adamawa State, northeastern Nigeria. The minerals and elemental compositions of the rock samples were determined using X-ray diffractometer (XRD) and X-ray fluorescence (XRF) instruments respectively. Results of the mineral composition of the rock samples showed (in order of abundance) the presence of quartz, albite, annite, and microcline, as well as orthoclase, phlogopite, oligoclase, chrysotile, and cordierite which were sparsely found in the study area. The abundant presence of silicate and aluminum silicate minerals in the study area was also shown in the major elemental composition of the rock samples, which follow the order SiO_2 (55.76 – 63.81%) > Al_2O_3 (11.06 - 13.15%) > Fe_2O_3 (8.41 – 11.2%) > K_2O (6.12 – 7.75%) > CaO (2.29 – 6.37%) > Na_2O (2.4%) > MgO (0.09 - 2.2%) > SO_3 (0.37 – 1.05%). The minor elements in the rocks include PbO, TiO_2, BaO, CuO, ZnO, P_2O_5, ZrO_2, Rb_2O, MnO, and Cl. The mineral and elemental compositions of the soil in the study area show similarities that link the origin of the soil to the weathering of the rocks. The geo-chemical data provided in this study will make an important contribution to both the literature and the database for future mining prospects in the study area.

Introduction

Rocks are combinations of solid minerals, which are natural components of the environment. Solid minerals are natural inorganic materials with a specific range of chemical and physical characteristics [1, 2].

Beyond industrial and material applications, components of rocks may also constitute green and sustainable energy potentials, which may require comprehensive evaluation and exploration for adequate conservation and utilization [3-6].

**Corresponding Author:* *Ayodele. Akinterinwa.* ayoterinwa@yahoo.com/ayoterinwa@mau.edu.ng

Therefore, the chemical composition of rocks can be used as the basis for studying their economic potential in different fields of application and valuation. Soil can be basically described as disintegrated rocks in disproportionate mixture with organic matter, water, air, biotic, and abiotic components that may be capable of supporting plant life [7-9].

The economic potential of Africa still lies deeply in its ability to maximize the exploration and profits of the vast variety of minerals that are naturally deposited in countries within the boundaries of the continent. It has been estimated that about 90%, 81%, 62%, 70%, 50%, and 30% of the global deposits of diamond, cobalt, platinum, gold, chromium, and copper respectively are seated in Africa [10]. Nigeria is an economic giant in Africa, and the sources of wealth of the nation remain majorly tied to natural resources [11-13].

Nigeria has continued to rank high among the ten largest crude oil producers in the world [14]. However, before the discovery of oil in Nigeria in 1964, exploration and mining of solid minerals such as coal, tin, columbite, lead, gold, and zinc were on a commercial scale [15,16].

The Geological Survey of Nigeria, which was established in 1919, was saddled with the continued survey of solid mineral deposits in the country [17,18]. Nevertheless, the geochemical data for a significant portion of Nigeria is yet to be established [19].

According to Vision 2020 of the National Technical Group working on minerals and metals development, as re-presented by Falade and Adeyeye, [17], the entire northeastern Nigeria, which includes Adamawa State, is less dense with mineral deposits. However, this report may not be substantive because the geochemical data of a vast proportion of northeastern Nigeria is yet to be adequately studied and established.

Evaluation of geochemical data of the rocks and soil in an area may unlock the resource potential of the area. The knowledge of elemental composition in rocks may provide important information about the minerals that are abundant in the core of the rock [20,21]. Potential maps for rock minerals in the Southern New England Orogen, New South Wales, and Australia were created based on mineral model systems and high-quality geochemical data [22].

The mineral system models and geochemical data were summarily evaluated by: (1) a spatial data table detailing the translation of the mineral model system, (2) the predictive maps that capture the mappable components of the targeted mineral system, and (3) the final mineral potential maps to develop the mineral system atlas [22]. Solid minerals are of vast industrial profitability [23].

Therefore, survey, development, and the final exploration of solid minerals are significant steps in the economic diversification and progression of a nation. Solid mineral deposits also vary over a very wide range of useful varieties. Evaluation and monitoring of chemical components of rock in the environment may also be used to monitor the effect of natural and anthropogenic activities on the chemical content of the rocks [7,24-27].

The lichen-mineral system was modeled to identify the fundamental interactions between microorganisms and solid minerals in rock [7]. It was further reported that fungi and other microorganisms involved in the interaction induced mineral disaggregation, hydration, dissolution, and secondary mineral formation, directly or indirectly, due to the release of organic acids and dissolved metabolic byproducts from the microorganisms [7]. The effects of field-induced changes in the pH of the rock reservoir environment on the chemistry of rock minerals were studied by Mohammed *et al.* [27]. Calcite, feldspar, barite, dolomite, and quartz, were studied in the research, and it was concluded that the changes in pH of the rock's reservoir environment alter the minerals wettability by controlling the development of charges on the minerals surface via mineral dissolution, ionic specie adsorption, and double-layer compression [27]. This therefore necessitates the progressive search and evaluation of all potential deposits of solid minerals.

About two decades ago, independent research focused on the determination of mineral composition as well as the associated major (> 1%) and minor (≤ 1%) elemental composition of rocks and soil in Adamawa State and other northeastern regions have opened a new chapter in the establishment of the geochemical data of the region [9,19,21,28-30]. Following this trend in our previous studies, we have reported the minerals and elemental composition of rocks at Ditera and Waltadi, in the Song local government area, and the Sukur Hills in the Madagali local government area [23,31-32].

In this study, we evaluated the mineral and elemental oxide composition of top rock and soil from Bakin Dutse Hills, Madagali, Adamawa State, Nigeria. The mineral composition and the elemental oxides of the rock samples were analyzed using X-ray diffraction (XRD) and X-ray fluorescence (XRF) instruments, respectively. This study is also in furtherance of our previous studies [23,31-32]. The research was undertaken because no study was found (to the best of our knowledge) on the rocks and soil within Bakin Dutse Hills, Madagali, Adamawa State, Nigeria. The results will therefore make tangible contributions to the geochemical information of the area.

Materials and Methods

Basic tools such as an angler's tool, hammer, chisel, soil thief, steel pestle and mortar, spatula, and platinum crucibles were used in obtaining samples and in the sample preparations. Acid (H_2SO_4 and HCl) and base (NaOH and NH_3OH) used were products of MERCK Chemicals Limited. X-ray diffraction and X-ray fluorescence spectrophotometer instruments were used for the mineral and elemental analysis, respectively.

Study Area

Bakin dutse rocks lay within latitude 10^0 51"N and longitude13^0 47" E. Bakin Dutse is located near Gulak in the Madagali local government area of Adamawa State, Nigeria. A topographical map of the area is displayed in Figure1.

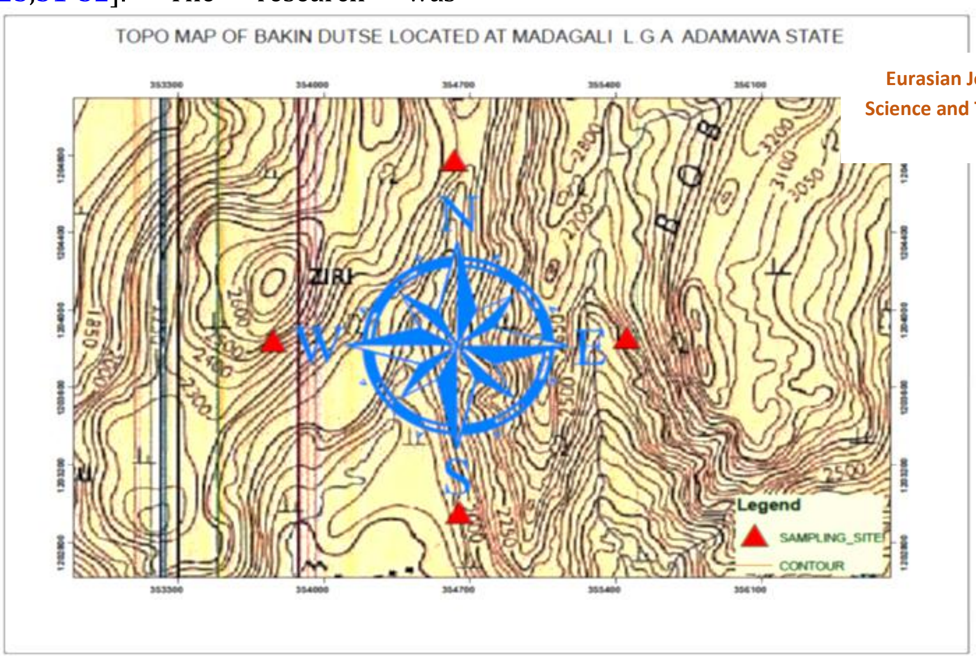


Figure 1 Topographical map of Barkin Dutse rocks

Table 1 Rock and soil samples and sample locations at Bakin Dutse rocks

S/N	Sample locations	Sample code names
1	Bakin dutse East Rock	BER
2	Bakin dutse North Rock	BNR
3	Bakin dutse South Rock	BSR
4	Bakin dutse Top-center Rock	BTR
5	Bakin dutse West Rock	BWR
6	Bakin dutse East Soil	BES
7	Bakin dutse North Soil	BNS
8	Bakin dutse South Soil	BSS
9	Bakin dutse Top-center Soil	BTS
10	Bakin dutse West Soil	BWS

Sampling Locations

Rock and soil samples were collected from five locations randomly selected on and around the Bakin Dutse rocks. Sampling locations were marked to adequately represent a quantitative top sample of the entire area. The samples were designated according to their location, as presented in Table 1.

Sample Collection and Treatment

Rock samples were collected according to methods reported in our previous study [23]. About 1 cm of the rock surface was scraped before samples were chiseled to a depth of about 10 cm. Soil samples were collected from soil around the same location as the rocks. Soil samples were taken at about 30 cm depth using a soil thief. Samples were labeled at the points of collection and transferred to the laboratory in clean polyethylene bags. Samples were sequentially watched with dilute acids (0.01 M H_2SO_4 and 0.01 M HCl), base (0.05 M NaOH and 0.05 M NH_3OH), and then three times with distilled water prior to drying under the sun for 12 hours. After drying, samples were crushed and grinded using a steel pestle and mortar and further sieved through a 10 µm mesh to obtain fine powder with particles ≤ 10 µm. The powdered samples were packed in 25 Gm bottles and labeled for instrumental analysis.

Analyses of Rock and Soil Samples

The mineral compositions of the powdered samples were analyzed using a Rayon X-ray diffraction (XRD) spectrometer (PANanalytical Empyrean, Netherlands). The elemental composition of samples was evaluated using X-ray fluorescence (XRF) spectrometer analysis (Energy Dispersive X-Ray Fluorescence spectrometer miniPal 4 PANanaltical). The conditions of instrumental analyses are the same as reported in the previous study [23]. For XRD, 0.35 g of powdered sample was introduced into the sample container of the XRD instrument. The X-ray light wavelength was 1.5 Å, and the diffraction angles (2Θ) were recorded between 0.5 and 100°. Minerals were identified via instruments in-built computation (according to Braggs equation $n\lambda = 2d\sin\Theta$) and library references (d-spacing). For XRF, 2.0 g of powdered sample was mixed with 0.4 g of stearic acid as a binder for the sample pellets mounted onto the instrument for the scans.

Results and Discussion

XRD spectra of rock samples from the study area are depicted in Figure 2. Nine minerals were identified in the rock samples from the study area. Quartz was most abundant in the area, as it was found in all five study locations, with a percentage range of 21% (BNR)-39% (BER). The abundance of quartz has been consistently reported in the rocks studied in the northeastern part of Nigeria, and this study remains consistent with the reported trend [19,21,23,28-29,31-32].

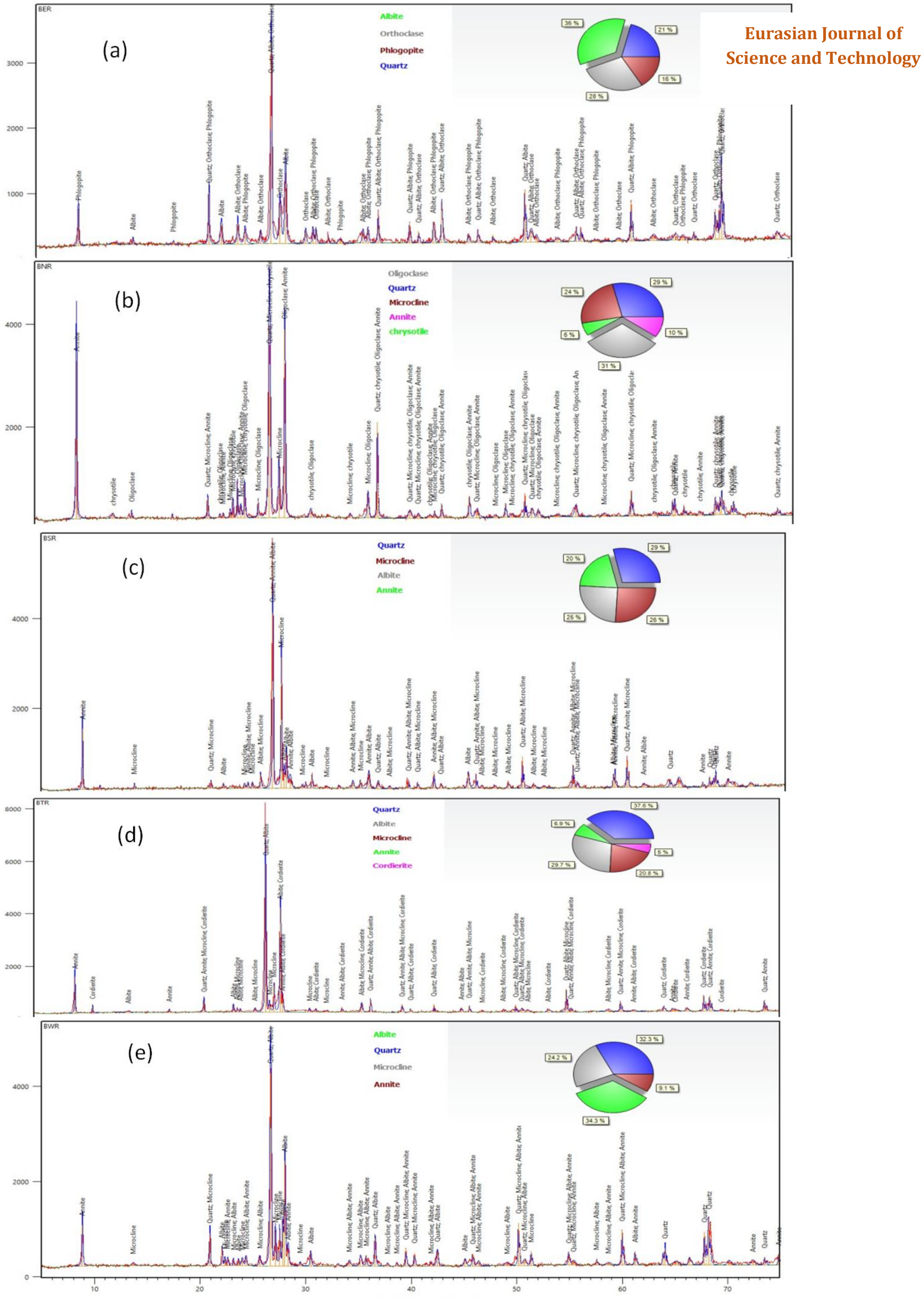
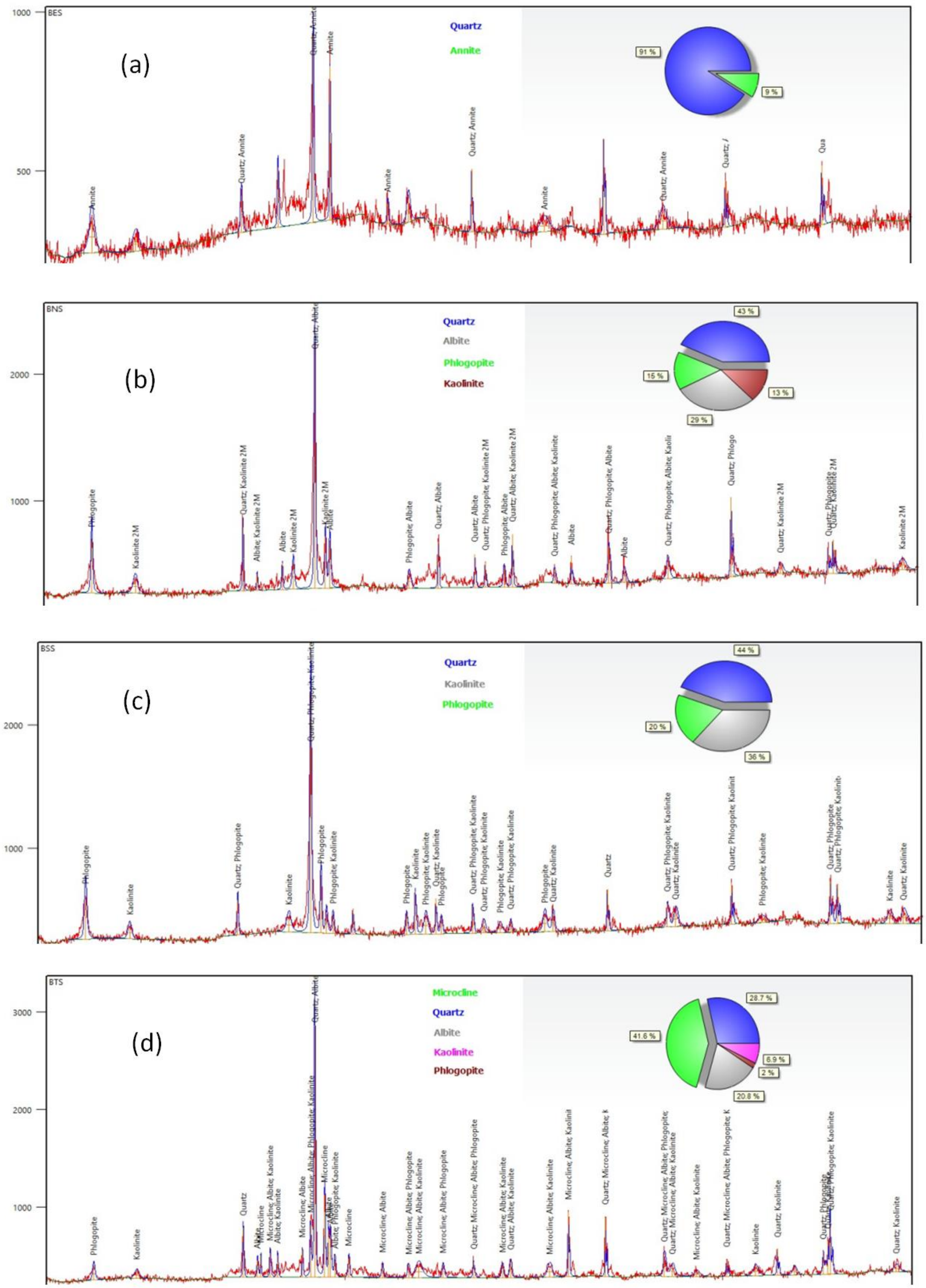


Figure 2 X-ray diffraction spectra of (a) BER, (b) BNR, (c) BSR, (d) BTR, and (e) BWR

Table 2 Characteristics of minerals identified in Bakin Butse rock samples

Location	Minerals_identified	Compound_name	Chemical_formula	Density g/cm^3	Crystal system	%composition
BER	Albite	Sodium Aluminium Silicate	$Na_{1.96}Ca_{0.04}Si_{5.96}Al_{2.04}O_{16.00}$	2.62	Anorthic	35.0
	Orthoclase	Potassium Aluminium Silicate	$K_{4.00}Al_{4.00}Si_{12.00}O_{16.00}$	2.56	Monoclinic	28.0
	Quartz	Silicon Oxide	$Si_{3.00}O_{6.00}$	2.65	Hexagonal	21.0
	Phlogopite	Potassium Magnesium Aluminium Silicate Hydroxide	$K_{1.66}Na_{0.14}Ba_{0.10}Mg_{4.39}Fe_{1.61}Si_{5.34}Al_{2.66}O_{23.66}.F_{0.34}H_{3.11}$	2.96	Monoclinic	16.0
BNR	Oligoclase	Sodium Calcium Aluminium Silicate	$Na_{1.45}Ca_{0.55}Al_{2.55}Si_{5.45}O_{16.00}$	2.65	Anorthic	31.0
	Quartz	Silicon Oxide	$Si_{3.00}O_{6.00}$	2.26	Hexagonal	39.0
	Microcline	Potassium Aluminium Silicate	$K_{1.90}Na_{0.10}Al_{2.00}Si_{6.00}O_{16.00}$	2.56	Anorthic	24.0
	Annite	Potassium Iron Aluminium Silicate	$Si_{5.68}Al_{4.26}Fe_{3.88}K_{1.80}O_{24.00}$	3.06	Monoclinic	10.0
	Chrysotile	Magnesium Silicate	$Mg_{12.00}Si_{8.00}O_{36.00}$	2.51	Monoclinic	6.0
BSR	Quartz	Silicon Oxide	$Si_{3.0}O_{6.00}$	2.65	Hexagonal	29.0
	Microcline	Potassium Aluminium Silicate	$K_{1.9}Na_{0.10}Al_{2.0}Si_{6}O_{16.0}$	2.56	Anorthic	26.0
	Albite	Sodium Aluminium Silicate	$Na_{2.0}Al_{2.0}Si_{6.0}O_{16.0}$	2.64	Anorthic	25.0
	Annite	Potassium Magnesium Iron Aluminium Silicate	$K_{1.86}Na_{0.14}Mg_{2.04}Fe_{2.82}Ti_{0.92}Al_{2.56}Si_{5.44}O_{24.0}$	3.16	Monoclinic	20.0
BTR	Quartz	Silicon Oxide	$Si_{3.0}O_{6.0}$	2.65	Hexagonal	37.6
	Albite	Sodium Aluminium Silicate	$Na_{2.0}Al_{2.0}Si_{6.0}O_{16.0}$	2.64	Anorthic	29.7
	Microcline	Potassium Aluminium Silicate	$K_{1.9}Na_{0.1}Al_{2.0}Si_{6.0}O_{16.0}$	2.56	Anorthic	20.8
	Annite	Potassium Iron Aluminium Silicate	$Si_{4.64}Al_{6.31}Fe_{3.25}K_{1.36}O_{24.0}$	3.10	Monoclinic	6.9
	Cordierite	Magnesium Aluminium Silicon	$Mg_{3.0}Al_{16.00}Si_{2.0}O_{72.0}Bi_{0.46}$	2.61	Orthorhombic	5.0
BWR	Albite	Sodium Aluminium Silicate	$Na_{1.96}Ca_{0.04}Si_{5.96}Al_{2.04}O_{16.0}$	2.62	Anorthic	34.3
	Quartz	Silicon Oxide	$Si_{3.0}O_{6.0}$	2.65	Hexagonal	32.3
	Microcline	Potassium Aluminium Silicate	$K_{1.90}Na_{0.10}Al_{2.0}Si_{6.0}O_{16.0}$	2.56	Anorthic	24.2
	Annite	Potassium Magnesium Iron Aluminium Silicate	$K_{1.86}Na_{0.14}Mg_{2.04}Fe_{2.86}Ti_{0.92}Al_{2.56}Si_{5.44}O_{24.0}$	3.18	Monoclinic	09.11

To basically evaluate the mineral composition of the soil in comparison with the rock at the location, soil samples from the rock locations were also analyzed. Figure 3 demonstrates the XRD spectra of the soil samples analyzed. The results showed that quartz maintained dominance, as it was found in all soil samples. Albite, annite, and microcline also reoccur in some of the soil samples from the study locations. However, there was a marked increase in the occurrence of phlogopite (found in four out of the five locations studied) and the emergence of kaolinite (which was not found in any of the rock samples) compared to the rock samples. The result showed that the soil in the study area may have been formed significantly from the weathering and metamorphosis of the rocks. Phlogopite has been well reported to be formed from the metamorphosis of rock minerals [36,38]. Kaolinite has also been reported to be formed from the hydrothermal transformation of aluminosilicate minerals such as orthoclase, oligoclase, chrysotile, and cordierite, which were found in some locations of the rocks but not in any soil sample [39-40]. Therefore, the presence of phlogopite, and


BES
(a)
Quartz
Annite
91 %
9 %
1000
500
BNS
(b)
Quartz
Albite
Phlogopite
Kaolinite
43 %
15 %
13 %
29 %
2000
1000
BSS
(c)
Quartz
Kaolinite
Phlogopite
44 %
20 %
36 %
2000
1000
BTS
(d)
Microcline
Quartz
Albite
Kaolinite
Phlogopite
28.7 %
41.6 %
6.9 %
2 %
20.8 %
3000
2000
1000

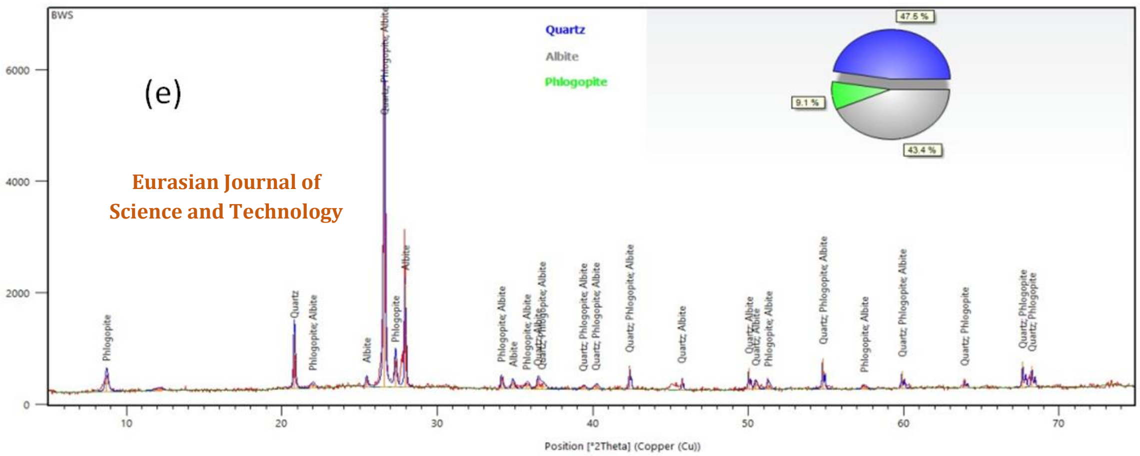


Figure 3 X-ray diffraction spectra of (a) BES, (b) BNS, (c) BSS, (d) BTS, and (e) BWS

Table 3 Characteristics of minerals identified in Bakin Butse soil samples

Location	Minerals identified	Compound_name	Chemical formula	Density g/cm³	Crystal system	%composition
BES	Quartz	Silicon Oxide	$Si_{3.0}\ O_{6.0}$	2.65	Hexagonal	91.0
	Annite	Potassium Iron Aluminium Silicate	$Si_{5.10}\ Al_{6.9}\ Fe_{6.0}\ K_{1.98}\ Na_{0.02}\ O_{24.0}$	3.69	Monoclinic	9.0
BNS	Quartz	Silicon Oxide	$Si_{3.0}\ O_{6.0}$	2.64	Hexagonal	43.0
	Albite	Sodium Aluminium Silicate	$Na_{1.96}\ Ca_{0.04}\ Si_{5.96}\ Al_{2.04}\ O_{16.0}$	2.62	Anorthic	29.0
	Phlogopite	Potassium Magnesium Iron Flora Aluminium Silicate	$K_{1.84}\ Na_{0.08}\ Mg_{3.12}\ Fe_{2.34}\ Ti_{0.29}\ Mn_{0.12}\ Si_{5.94}\ AL_{2.01}\ O_{22.12}\ F_{1.88}$	3.12	Monoclinic	15.0
	Kaolinite	Aluminium Silicate	$Al_{8.0}\ Si_{8.0}\ O_{36.00}$	2.57	Monoclinic	13.0
BSS	Quartz	Silicon Oxide	$Si_{3.0}\ O_{6.00}$	2.64	Hexagonal	44.0
	Kaolinite	Aluminium Silicate Hydroxide	$Al_{2.0}\ Si_{2.0}\ O_{9.00}\ H_{4.00}$	2.61	Anorthic	36.0
	Phlogopite	Potassium Magnesium Titanium Iron Aluminium Silicate	$K_{3.56}\ Na_{0.28}\ Mg_{6.0}\ Fe_{4.44}\ Ti_{1.56}\ Al_{4.48}\ Si_{11.52}\ O_{48.00}$	3.07	Monoclinic	20.0
BTS	Microcline	Potassium Aluminium Silicate	$K_{1.90}\ Na_{0.10}\ Al_{2.0}\ Si_{6.00}\ O_{16.00}$	2.56	Anorthic	41.6
	Quartz	Silicon Oxide	$Si_{3.00}\ O_{6.00}$	2.65	Hexagonal	28.7
	Albite	Sodium Aluminium Silicate	$Na_{1.96}\ C_{0.04}\ Si_{5.96}\ Al_{2.04}\ O_{16.00}$	2.62	Anorthic	20.8
	Kaolinite	Aluminium Silicate	$Al_{2.00}\ Si_{2.00}\ O_{9.00}$	2.56	Anorthic	6.9

	Phlogopite	Potassium Nickel Aluminium Silicate Hydroxide	$Al_{2.16}$ $Si_{5.84}$ $Ni_{6.00}$ $K_{20.00}$ $O_{240.0}$ $H_{4.00}$	3.50	Monoclinic	2.0
BWS	Quartz	Silicon Oxide	$Si_{3.00}$ $O_{6.00}$	2.64	Hexagonal	47.5
	Albite	Sodium Aluminium Silicate	$Na_{1.96}$ $Ca_{0.04}$ $Si_{5.96}$ $Al_{2.04}$ $O_{16.00}$	2.62	Anorthic	43.4
	Phlogopite	Potassium Magnesium Titanium Iron Aluminium Silicate	$K_{3.72}$ $Na_{0.28}$ $Mg_{6.00}$ $Fe_{4.44}$ $Ti_{1.56}$ $Al_{4.08}$ $Si_{11.02}$ $O_{48.00}$	3.09	Monoclinic	9.1

kaolinite in the soil can be attributed to the weathering and metamorphic processes of the rocks in the area. Table 3 complementarily lists the identified minerals, their elemental composition, and the characteristic crystal lattices.

The results of the elemental components of the rock samples presented as major (more than 1% of the rock) and minor (within 1 to 0.1% of the rock) elemental components are presented in Tables 4 and 5, respectively. The elemental compositions which are presented in their oxide forms show that SiO_2, Al_2O_3, Fe_2O_3, K_2O, CaO, MgO, SO_3, and Na_2O, were found at almost all locations in variable concentrations. SiO_2 is the most abundant component in the rock samples, which ranges from 55.76 to 63.81 %. This also agrees with the X-ray diffraction results, which indicated that quartz is the most abundant mineral at almost all locations. Furthermore, almost all the minerals detected in the rocks and soil are silicate minerals. In summary, the results range in the following sequence: $SiO_2 > Al_2O_3 > Fe_2O_3 > K_2O > CaO > Na_2O > MgO > SO_3$. The result of silicon oxide is closely followed in abundance by aluminum oxide within the range of 11.06 and 13.15 %; this is also in agreement with the X-ray diffraction result which shows that most of the minerals revealed are of aluminum silicate base. The results also show that the values for iron and potassium oxides are closely comparable and come after aluminum; they are also major components of the minerals detected by XRD in most of the rock samples, though potassium was recorded more than iron. The presence of sodium was observed at only one sample location, BER, where there is the presence of albite, a sodium base mineral. This also indicated that BER is the location with highest Na_2O-rich albite. The presence of SO_3 indicated that some sulfide and sulphosalt ore minerals, such as chalcosite Cu_2S, pyrite FeS_2, galena PbS, stibnite Sb_2S_3, and oldhamite CaS, which are susceptible to decomposition under mild conditions [41], are also present in the rock samples. These results agree with the fact that the eight most common elements making up the minerals found in the earth's crust are as follows: oxygen 46.6 %, silicon 27.7 %, aluminum 8.1 %, iron 5.0 %, calcium 3.6 %, sodium 2.8 %, potassium 2.6 % and magnesium 2.1 %, they are really the major elements and make up 98.5 % of the earth, while the remaining 1.5 % are the minor elements. The presence of sulfur oxide is negligible at most locations, indicating that there are no sulfate minerals in all the locations, which also agrees with the results of minerals identified in the area.

The results of the minor elemental oxides (Table 5) provide elements and elemental oxides that were detected in the locations within the study area. TiO_2 (titanium oxide), also known as rutile, is one of the hard rock minerals used for the formulation of text coat paints. It appeared to have remarkable values at all locations. Zinc oxide was detected at only one location, BER, in a minute quantity. This agrees with the XRD results, which show no trace of zinc mineral present at all locations. The results of barium oxide appeared to be comparatively high among the minor elements, especially at BER, but XRD results did not

Table 4 Percentage (%) composition of major elemental composition in rock samples from Bakin dutse

Location	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
BER	61.06	12.68	8.57	2.69	1.30	1.05	6.12	2.40
BNR	55.76	13.15	11.20	5.44	1.90	0.41	7.21	-
BSR	58.59	11.79	9.31	6.37	2.20	0.48	7.75	-
BTR	60.70	12.33	9.72	4.97	0.90	0.51	7.41	-
BWR	63.81	11.06	8.41	3.59	1.50	0.37	7.06	-
Range	55.76	11.06	8.41	2.69	0.90	0.37	6.12	-
	63.81	13.15	11.20	6.37	2.20	1.05	7.75	2.40

Table 5 Percentage (%) composition of minor elemental composition in rock samples from Bakin Dutse

Location	TiO_2	BaO	ZnO	P_2O_5	ZrO_2	Rb_2O	MnO	Cl
BER	0.42	2.06	0.07	0.33	0.62	0.06	0.13	0.14
BNR	2.34	0.15	-	1.35	0.20	0.05	0.18	0.33
BSR	1.41	0.17	-	1.04	0.12	-	0.17	0.32
BTR	1.44	0.08	-	0.44	0.51	0.07	0.17	0.34
BWR	1.94	0.19	-	1.12	-	-	0.13	0.33
Range	0.42	0.08	0.07	0.33	0.12	0.05	0.13	0.14
	2.34	2.06	-	1.35	0.62	0.07	0.18	0.34

Range = Limits between values, - = Not detected.

indicate that there is $BaSO_4$ (barite) in the sample area, which suggests that the deposits may not be high enough for detection by the XRD instrument. Chlorine (in chloride forms) is a typical component of many minerals, they are combined in trace amount and they are typically not involved in their major crystal lattice on the mineral.

The results of the major and minor elemental components of soil samples from Bakin Dutse are presented in Tables 6 and 7, respectively. In similarity to the rock samples, silica (SiO2) appeared as the most abundant mineral available at all the locations, ranging between 46.46 and 55.20 %. Aluminum and Iron oxides appeared competitively at most locations, ranging between 17.43-19.37% and 8.63-18.69%, respectively. Potassium oxide also appeared quantitatively high, a little bit higher than calcium within the range of 5.82 to 7.20%, compared to the results of the rock samples. Sulfur oxide sparingly appeared, just like the results for the rock samples at all the locations. This also indicated that there are traces of some sulfide and sulphosalt ore minerals in all the locations. Sodium oxide did not appear at all in all the soil samples. The results of the major elemental oxides in soil are in the following sequence; $SiO_2 > Al_2O_3 > Fe_2O_3 > K_2O > CaO > MgO > SO_3$. The order of the major elemental oxides in the soil is the same as that obtained for the rock samples in Bakin Dutse. This indicated that the origin of the soil in the area can be linked to the rock. Isaac *et al.* [9] reported that the major oxides in Mambila plateau soil which is also in the northeastern region, follows the order $SiO_2 > Al_2O_3 > TiO_2 > CaO > K_2O$. The study showed TiO_2 as a major oxide and a higher amount of CaO than K_2O, which are in contrast to the results in this study.

The minor elemental composition (Table 7) showed that TiO_2 appeared appreciably within the range 1.32- 3.0 %, followed by P_2O_5 at a range of 0.83-1.94 %. The presence of PbO, CuO, and ZnO were not detected at all in the soil samples. Similar to the rock samples, the presence of chlorine was detected at all the locations sparingly within the range of 0.26-0.33 %. BaO also appeared at all the locations,

Table 6 Percentage (%) composition of major elemental composition in soil samples from Bakin Dutse

Location	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
BES	46.55	17.43	17.04	4.13	2.70	0.65	5.82
BNS	46.46	19.37	18.69	3.09	2.70	0.58	5.91
BSS	47.15	18.94	16.53	3.34	2.50	0.53	5.87
BTS	55.20	17.96	8.63	4.92	2.00	0.61	6.37
BWS	51.46	18.48	12.67	2.71	2.00	0.45	7.20
Range	4.46	17.43	8.63	2.71	2.00	0.45	5.82
	55.20	19.37	18.69	4.92	2.70	0.65	7.20

Range = Limits between values, - = Not detected.

Table 7 Percentage (%) composition of minor elemental oxides in soil samples from Bakin Dutse

Location	TiO_2	BaO	P_2O_5	ZrO_2	Rb_2O	MnO	Cl
BES	3.00	0.28	1.21	0.24	-	0.27	0.33
BNS	2.91	0.18	0.91	0.25	0.05	0.29	0.33
BSS	2.89	0.33	0.83	0.22	-	0.28	0.33
BTS	1.32	0.06	1.94	0.25	0.08	0.19	0.26
BWS	2.71	0.27	0.86	0.29	0.07	0.21	0.27
Range	1.32 - 3.00	0.06-0.33	0.83-1.94	0.22-0.29	0.05-0.08	0.19-0.29	0.26-0.33

Range = Limits between values, - = Not detected.

but in small quantities ranging between 0.06-0.33 %. In summary, the sequence appears as $TiO_2 > P_2O_5 > BaO > ZrO_2 > MnO > Rb_2O$. Compared to the minor components in Bakin Dutse rocks, PbO, CuO, ZnO, Mn and Cl were not found in the soil. This can be attributed to complete leach-out of these minor components during the weathering of the origin rock to form the soil. Fe_2O_3 was recorded as a major component in this study, while Isaac *et al.* [9], reported Fe_2O_3 as a minor composition of the Mambila plateau soil. This contrast in the amount and order of composition of these compounds can be attributed to different modes of rock weathering. This can be caused by significant difference in mobility of the cations, resulting from the difference in climatic conditions in different locations with the region [42,43].

Conclusion

This study presented the minerals and elemental composition of the rock and soil within the Barkin Dutse hills in Adamawa State, Nigeria. The mineral and elemental compositions of the rock samples from the study area showed the presence (in order of their abundance) of quartz, albite, annite, microcline, orthoclase, phlogopite, oligoclase, chrysotile, and cordierite. The soil sample showed the presence of kaolinite in addition to the minerals recorded in the rocks. The emergence of kaolinite in the soil was attributed to the metamorphosis of the rock's aluminosilicate minerals, such as orthoclase, oligoclase, chrysotile, and cordierite. In general, the results showed similarities to previous studies on the analysis of rocks in the northeastern region of Nigeria, within which the study area falls. The complimentary elemental analyses provided results that are in accordance with the minerals in the study locations. The results obtained in this study will form part of the mineral survey of the northeastern region of Nigeria and make contributions to the geochemical data buildup for the region.

Acknowledgements

The authors acknowledge the professional and technical guidance as well as mentorship provided by Professor Humphrey M. Maina of

the Department of Chemistry, Modibbo Adama University Yola, Nigeria.

References

[1] Pipkin B.W., Trent D.D., Hazlett R., Bierman P., Cengage Learning, 2013 [Google Scholar]

[2] Zuev B.Y., Zubov V., Fedorov A., Application prospects for models of equivalent materials in studies of geomechanical processes in underground mining of solid minerals, *Eurasian mining*, 2019, **1**:12 [Google Scholar], [Publisher]

[3] Uhlík J., Baier J., *Mine Water and the Environment*, 2012, **31**:179 [Crossref], [Google Scholar], [Publisher]

[4] Masok F.B., Masiteng P.L., Mavunda R.D., Maleka P.P., Health effects due to radionuclides content of solid minerals within port of Richards Bay, South Africa, *International journal of environmental research and public health*, 2016, **13**:1180 [Crossref], [Google Scholar], [Publisher]

[5] Oduh I.O., Joseph S.R., Olarinoye O., Kolo M., Evaluation of radioactivity concentration of some selected mineral rocks from Mayo-Belwa Local Government Area of Adamawa State, Nigeria, 2022, [Crossref], [Google Scholar], [Publisher]

[6] El Alami K., Asbik M., Boualou R., Ouchani F.z., Agalit H., Rachidi S., A critical overview of the suitability of natural Moroccan rocks for high temperature thermal energy storage applications: Towards an effective dispatching of concentrated solar power plants, *Journal of Energy Storage*, 2022, **50**:104295 [Crossref], [Google Scholar], [Publisher]

[7] Banfield J.F., Barker W.W., Welch S.A., Taunton A., Biological impact on mineral dissolution: application of the lichen model to understanding mineral weathering in the rhizosphere, *Proceedings of the National Academy of Sciences*, 1999, **96**:3404 [Crossref], [Google Scholar], [Publisher]

[8] Lebgue-Keleng T., Aviña-Domínguez Y.E., Soto-Cruz R.A., Quiñonez-Martínez M., Cortés-Palacios L., Melgoza-Castillos A., Morales-Nieto C., Vélez-Sanchez-Verin C., Balderrama-Castañeda S., Soil mineralogy and its relationship with cacti species in southeastern Chihuahua, México, *Ecología Aplicada*, 2014, **13**:ág. 205 [Crossref], [Google Scholar], [Publisher]

[9] Isaac E., Maitera O., Donatus R., Riki Y., Yerima E., Tadzabia K., Joseph B., Energy dispersive X-Ray fluorescence determination of minor and major elements in soils of Mambilla Plateau Northeastern Nigeria, *Journal of Environmental Chemistry and Ecotoxicology*, 2019, **11**:22 [Google Scholar], [Publisher]

[10] Okorafor M.O., *International Journal of Science and Technology*, 2014, **3**:461 [Google Scholar]

[11] Kashim I.B., Solid Mineral Resource Development in Sustaining Nigeria's Economic and Environmental Realities of the 21st Century, *Journal of Sustainable Development in Africa*, 2011, **13**:210 [Google Scholar], [Publisher]

[12] Danmola R.A., Wakili A. M., *Journal of Emerging Trends in Economics and Management Sciences*, 2013, **4**:533 [Google Scholar], [Publisher]

[13] Dada J.T., Adeiza A., Noor A.I., Marina A., Investigating the link between economic growth, financial development, urbanization, natural resources, human capital, trade openness and ecological footprint: evidence from Nigeria, *Journal of bioeconomics*, 2022, 1 [Crossref], [Google Scholar], [Publisher]

[14] Hosseini S., Lawal A.I., Kwon S., A causality-weighted approach for prioritizing mining 4.0 strategies integrating reliability-based fuzzy cognitive map and hybrid decision-making methods: A case study of Nigerian Mining Sector, *Resources Policy*, 2023, **82**:103426 [Crossref], [Google Scholar], [Publisher]

[15] Olade M., Solid mineral deposits and mining in Nigeria: a sector in transitional change, *Achievers Journal of Scientific Research*, 2019, **2**:1 [Google Scholar], [Publisher]

[16] Ifem L.A., Obianagwa C.E., Eze N.U., Nwannennaya C., Ereforokuma O.N., The paradox of poverty in plenitude: X-raying the impact of 2017 economic recovery and growth plan on solid minerals industry in Nigeria, *Journal of Economics and Allied Research*, 2021, **6**:132 [Google Scholar]
[17] Falade M., Adeyeye P., A profile of Nigeria's solid minerals a detailed desk review, *Lagos, Nigeria: Centre for Public Policy Alternatives (CPPA)*, 2016 [Google Scholar], [Publisher]
[18] Iheukwumere S.O., Nkwocha K.F., Tonnie-Okoye N., Agulue E., *International Journal of Geography and Environmental Management*, 2020, **6**:49 [Google Scholar], [PDF]
[19] Zanna H., Maina H., Maitera, O., Solid Mineral Status in Rocks of Akko Local Government Area, Gombe State, Nigeria, 2017, [Google Scholar], [Publisher]
[20] S.J. Manroe, R. Wadworth USA, 3rd Ed., 1998, pp. 35-60. ISBN 13: 978-0534537753 [PDF]
[21] Ford A., Peters K., Partington G., Blevin P., Downes P., Fitzherbert J., Greenfield J., Translating expressions of intrusion-related mineral systems into mappable spatial proxies for mineral potential mapping: Case studies from the Southern New England Orogen, Australia, *Ore Geology Reviews*, 2019, **111**:102943 [Crossref], [Google Scholar], [Publisher]
[22] Alexander P., Maina H., Barminas J., Quality of Solid Minerals in Rocks and Soils of Mubi South Local Government Area of Adamawa State, Nigeria, *International Research Journal of Pure and Applied Chemistry*, 2016, **10**:1 [Google Scholar], [Publisher]
[23] Benson A., Akinterinwa A., Milam C., Maina H.M., Assessment of Solid Minerals and Elemental Composition of Rocks and Soil Samples from Sukur Hillis, Madagali, Nigeria, *Journal of Scientific Research (JSR)*, 2023, **2** [Google Scholar], [Publisher]
[24] Badmus B., Olurin O., Ganiyu S., Oduleye O., Evaluation of physical parameters of various solid minerals within southwestern Nigeria using direct experimental laboratory methods, *American International Journal of Contemporary Research*, 2013, **3**:152 [Google Scholar], [Publisher]
[25] Wray R.A., Sauro F., An updated global review of solutional weathering processes and forms in quartz sandstones and quartzites, *Earth-Science Reviews*, 2017, **171**:520 [Crossref], [Google Scholar], [Publisher]
[26] Powell R., Evans K.A., Green E.C., White R.W., The truth and beauty of chemical potentials, *Journal of Metamorphic Geology*, 2019, **37**:1007 [Crossref], [Google Scholar], [Publisher]
[27] Mohammed I., Al Shehri D.A., Mahmoud M., Kamal M.S., Alade O., Surface charge investigation of reservoir rock minerals, *Energy & fuels*, 2021, **35**:6003 [Crossref], [Google Scholar], [Publisher]
[28] Alexander P., Maina H.M., Barminas J.T., Zira S.P., *Journal of Sciences and Multidisplinary Research*, 2011, **3**:23 [Google Scholar], [Publisher]
[29] Penuel B., Maitera O., Khan M., Ezekiel Y., X-Ray Diffraction Characterization of Sedimentary Rocks in Demsa Local Government Area of Adamawa State, Nigeria, *Current Journal of Applied Science and Technology*, 2017, **24**:1 [Crossref], [Google Scholar], [Publisher]
[30] Joseph B., Maina H.M., Milam C., Donatus R.B., Isaac E., *Global Scientific Journal*, 2022, **10**:2145 [PDF]
[31] Osemeahon S., Maitera O., Aliyu B., Survey of Solid Minerals in Rocks of Ditera and Waltadi, Song, Nigeria, *Environment and Natural Resources Research*, 2015, **5**:30 [Google Scholar]
[32] Benson A., Akinterinwa A., Milam C., Maina H.M., *Journal of Scientific Research,* 2023, 2, 1-15. [Crossref], [Google Scholar], [Publisher]

[33] Obaje N.G., Geology and mineral resources of Nigeria, *Journal*, 2009, **120** [Crossref], [Google Scholar], [Publisher]
[34] Chukwu A., Obiora S.C., Geochemical constraints on the petrogenesis of the pyroclastic rocks in Abakaliki basin (Lower Benue Rift), Southeastern Nigeria, *Journal of African Earth Sciences*, 2018, **141**:207 [Crossref], [Google Scholar], [Publisher]
[35] Ahmed H.A., Halilua M., Salisua I.A., Vandia D.K., *IJRDO-Journal of Applied Science,* 2017, **3**:63
[36] Hobart M.K., *Geoscience News and Information: Geology.com*, 2011, 1-4. [Crossref], [Publisher]
[37] Cudahy T., Caccetta M., Thomas M., Hewson R., Abrams M., Kato M., Kashimura O., Ninomiya Y., Yamaguchi Y., Collings S., Satellite-derived mineral mapping and monitoring of weathering, deposition and erosion, *Scientific Reports*, 2016, **6**:23702 [Crossref], [Google Scholar], [Publisher]
[38] Chatir A., Berger J., Ennih N., Triantafyllou A., de Parseval P., Errami E., Diot H., Baele J.M., Aghzer A.M., Monnier C., Formation of the Nkob talc deposit by contact metamorphism and fluid infiltration into siliceous dolostones (Moroccan Anti-Atlas), *Ore Geology Reviews*, 2022, **140**:104629 [Crossref], [Google Scholar], [Publisher]
[39] Huertas F.J., Fiore S., Huertas F., Linares J., Experimental study of the hydrothermal formation of kaolinite, *Chemical Geology*, 1999, **156**:171 [Crossref], [Google Scholar], [Publisher]
[40] Anderson R.P., Tosca N.J., Cinque G., Frogley M.D., Lekkas I., Akey A., Hughes G.M., Bergmann K.D., Knoll A.H., Briggs D.E., Aluminosilicate haloes preserve complex life approximately 800 million years ago, *Interface Focus*, 2020, **10**:20200011 [Crossref], [Google Scholar], [Publisher]
[41] Wedepohl K.H., Delevaux M.H., Doe B.R., The potential source of lead in the Permian Kupferschiefer bed of Europe and some selected Paleozoic mineral deposits in the Federal Republic of Germany, *Contributions to Mineralogy and Petrology*, 1978, **65**:273 [Crossref], [Google Scholar], [Publisher]
[42] Elliott C., Influence of temperature and moisture availability on physical rock weathering along the Victoria Land coast, Antarctica, *Antarctic Science*, 2008, **20**:61 [Crossref], [Google Scholar], [Publisher]
[43] Afolabi R.O., Orodu O.D., Efeovbokhan V.E., Properties and application of Nigerian bentonite clay deposits for drilling mud formulation: recent advances and future prospects, *Applied Clay Science*, 2017, **143**:39 [Crossref], [Google Scholar], [Publisher]