Journal of Advanced Research in Geo Sciences & Remote Sensing
Volume 7, Issue 1&2 - 2020, Pg. No. 17-23
Peer Reviewed Journal

Research Article

Monitoring of the Environmental Radioactivity at Elobeid Area, North Kordofan State, Sudan

Mohammed I Abdallsamed[1], Elhadi M Ibrahim[2], Mushaal A Salih[3], Mohammed A Elhadi[4], Ahmed D Mohammed[5], Hassan-A Mustafa[6], Asim A Elmansour[7], Mohammed B Hussein[8], Asha F Wady[9], Muna M Mohammed[10]

[1,3,5,6,7]Department of Geology, Faculty of Science, University of Kordofan, B160, El-Obeid, Sudan.
[4,10]Department of Geology, Faculty of Science, University of Gazira, Medani, Sudan.
[2,8,9]Department of Chemistry, Faculty of Science, University of Kordofan, B160, El-Obeid, Sudan.

I N F O

Corresponding Author:
Mohammed I Abdallsamed, Department of Geology, Faculty of Science, University of Kordofan, B160, Elobeid, Sudan.
E-mail Id:
mabdallsamed.geo@gmail.com
Orcid Id:
https://orcid.org/0000-0001-9187-3437
How to cite this article:
Abdallsamed MI, Ibrahim EM, Salih MA et al. Monitoring of the Environmental Radioactivity at Elobeid Area, North Kordofan State, Sudan. *J Adv Res Geo Sci Rem Sens* 2020; 7(1&2): 17-23.

Date of Submission: 2020-04-05
Date of Acceptance: 2020-05-11

A B S T R A C T

The present work deals with the monitoring of the radioactivity at Elobeid area, North Kordofan State, in the central Sudan. The ivestigation was done for the first time. Twelve basement rock samples were taken from three localities. The high resolution in situ gamma ray spectrometer system was used to examine the natural radioactivity levels. The mean weight values of the elemental and the activity concentration levels of ^{238}U and ^{40}K are 3.14 and 4.95 ppm with 39.7 and 1502 Bq/Kg in the migmatite gneisses, while the mean weight values and the activity concentration levels are 4.23 and 2.67 ppm with 52.5 and 809 Bq/Kg in the micaschist respectively. These results are conidered higher than the corresponding global average values proposed by United Nations Scientific Committee on the Effects of Atomic Radiation publications for normal radiation background areas, except the values for the ^{238}U in the migmatite gneiss, approves the global average values. The study area requires further investigation of soil geochemistry, and the activity concentration levels of radionuclides in soil and groundwater.

Keywords: Environmental Radioactivity, Gamma Ray Spectroscopy, Natural Radioactivity Levels, Geochemical Behavior, Basement Rocks, Elobeid Area

Introduction

Natural Occurring Radioactive Material (NORM) is found through the earth's crust, and they form part of the natural background radiation to which all humans are exposed (U.S. Environmental Protection Agency, 1993; Akingboye and Ademila, 2019). Although the Geological Materials (GM) contain Low-Level Radioactivity (LLR), however, the accumulated quantity can be high. Therefore, the GM is the most vital sources for the Natural Activity Concentration Levels (NACL) in the environment (U.S. Environmental Protection Agency, (1993); UNSCEAR, (1993); International Atomic Energy Agency (IAEA), 2003; Maxwell et al., 2013). The specific levels of the NACL depend, mainly on the local geological conditions and mineralogical composition of the rocks as well as the content of the radioelements (United Nations Scientific Committe on the effects of Atomic Radiation (UNSCEAR, 2000); Tennisseen, 1994; Xinwei and Xiaolon, 2008; El-Mageed et al., 2011; Florou and Kritidis, 1992; Anjos et al., 2005; Arafa, 2004). The radiation level of any geolological material depends upon the mineralogical composition, where higher radiation levels are generally associated with felsic rocks and lower levels with basic rocks

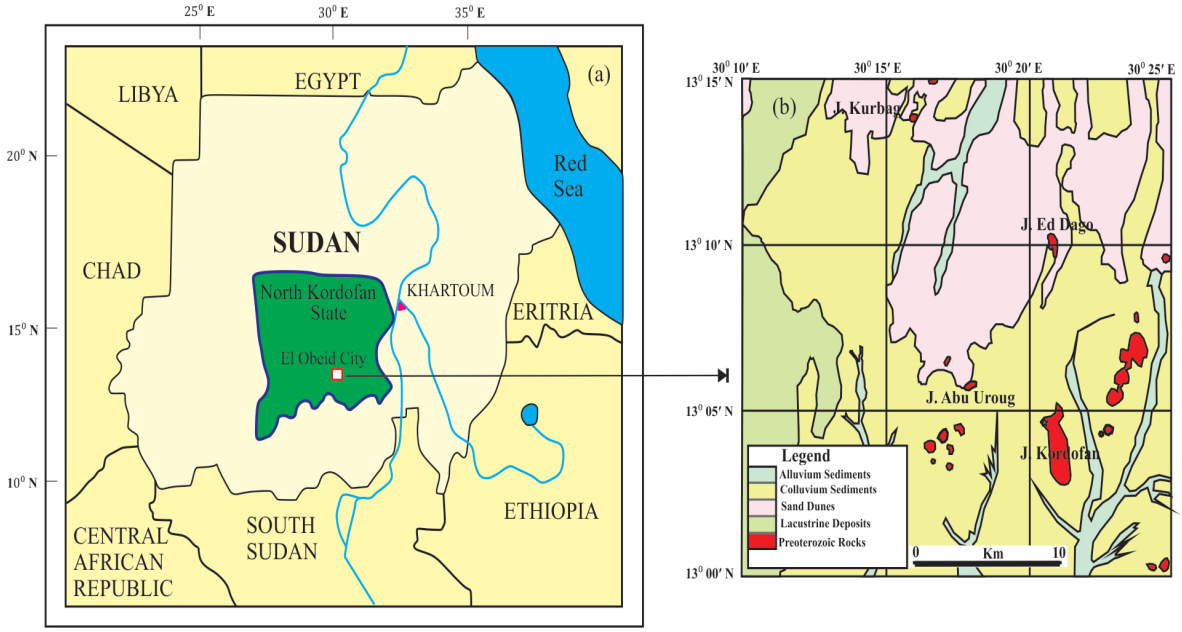
(Glover et al., 2014). The knowledge of concentrations and distributions of the NACL in geological materials provides useful information in the monitoring of environmental radioactivity (El-Mageed et al., 2011).

Golobally, in recent decades, extensive studies have been carried out to evaluate the risks associated with the NACL in different geochemical environment to establish base line data of natural radiation levels (e.g. U.S. Nuclear Regulatory Commission, NRC, 1988; United Nations Scientific Committe on the effects of Atomic Radiation, UNSCEAR, 2000; Ibrahiem et al., 1993; Quindos et al., 1994; Mireles et al., 2003). In Sudan a number of studies have been done for Natural Occurring Radioactive Materials (NORM) on environmental radioactivity since late 1980th after the math of Chernobyl accident (e.g., Mokhtar, 2003; Sam and Holm, 1995; Sam et al. 1997). Those studies are focused on producing radiation map for the country to be used as a reference in case of any radiological accident of global dimension. However, the most NORM levels have been reported from the soils and vegatiations. On the contrary, the measurements on NORM from the rock samples have received less attention.

Elobeid area represents a complex geological evolution of Basement rocks covered "locally" by a few meters thick of recent deposits. The interest in this installation mainly lies in its configuration and location. Morphologically, Elobeid area is situated within undulatyed surface, cutted by many valleyes and Wadies which make the Basement rocks to be subaerially exposed. Moreover, there are also farming and industrial activities which may locally exposed some Basement rocks in the area. Because of the mineralogical composition (e.g. Quartz, K-feldspar, plagioclase, muscovite and biotite), the Basement rocks are likely to contain high concentrations of natural radionuclides. Thus, the study of the natural radioactivity of the basement rocks in Elobeid area is an important subject in environmental radioactivity monitoring. Its provides the possibility to assess any changes in the radioactivity background level due to various activities involving radioactive materials (Anjos et al., 2005). The objective of this study, therefore, is to determine the natural background radioactivity levels in the lithological units.

Study Area and Geological Features

The study area is situated in Sheakan locality of North Kordofan State, Central Sudan (Figure 1a). Geologically, it represents part of the uplift block of pre-Cambrian basement rocks in the central Sudan. The Basement rocks North of Elobeid, are covered directly by Holocene deposits (Dawelbeit et al, 2019). Most of the Holocene deposits are of aeolian origin locally interrupted by fluvial and/or alluvial deposits, while in contrast, south of Elobeid the Basement rocks are covered mostly by alluvial deposits (Figure 1b). The metamorphic rocks are generally composed of gneisses and migmatite, micaschist, quartzite and amphibolite (Vail, 1973, 1978; Mustafa, 2007, Abdallsamed, 2010, Mustafa et al., 2018) of Pre-cambrian ages. All these rocks have been affected and deformed by the Pan-african thermo-tectonic event. Gneisses and migmatite are the major basement rocks that are abundantly available in the study area. It is distributed mainly in the Southern and Northern parts, running generally north to south along the length of the study area.



(a) **(b)**

Figure 1.(a)Location map of Elobeid Area; (b)Geological map

The field investigations (this study) have revealed that, the migmatite gneisis are mostly covered by recent sediments, and they exposed on the surface only in some isolated outcrops such as J. Kordofan, J. Abu Uroag and J. Kurbag (Figure 1b). They are usually grey to whitish in color in J. Kordofan and pinkish to grey of coarse texture in J. Kurbag and J. Abu Uroag. In thin section, they consist predominantly of Quartz, K-feldspar, plagioclase (oligoclase and andesine), muscovite, biotite, hornblende, iron oxides and apatite (Abdallsamed, 2010). The micaschists overlies unconformity the gneisses and migmatite, and are poorly exposed on the surface, mostly buried under a thick cover of recent sediments. They are well exposed on the surface in J. Kordofan, J. Abu Uroag and J. Kurbag, occurring as bands forming anticlinal and synclinal folds, having, a well developed schistosity. They are varying in color dark grey in J. Kordofan and grey of medium texture in J. Abu Uroag and J. Kurbag. The rocks in J. Abu Uroag are very poor in dark minerals.

Materials and methods

Sampling and Sample Preparation

The sampling areas were chosen on the basis of a field work. Three localities (J. Kordofan, J. Abu Uroag and J. Kurbag) were chosen and a total of 12 rock samples of about 1 kg were collected from the gneisses and migmatite and micaschist. Subsequently, the samples were transported to the Sudan Atomic Energy Commition Laboratory in Khartoum, Sudan for further analyses. The samples were crushed to powder and passed through 250 um sieve mesh with the help of sieve shaker. The fine powdered samples were homogenized, and carefully weighed using an electronic balance with sensitivity of 0.01 g. About 500 g of the homogenized fine powder from each sample was sealed in polyethylene bottles with a plastic cover and labeled accourding with the indelible marker. The samples were stored for six weeks to allow gaseous for the in-growth of ^{222}Rn (3.8 days half-life) and its short-lived decay products (^{214}Pb and ^{214}Bi) to attain radioactive equilibrium with its long-lived precursor ^{226}Ra (1600 year half-life) in the sample.

Measurements of ^{238}U and ^{40}K

The high-resolution in situ gamma-ray spectrometry presents further accessible information on environmental radioactiviy measurements. In this study, the activity concentration of ^{238}U and ^{40}K from metamorphic rocks samples were measured using gamma-ray spectrometry system equipped with high purity germanium detectors (HPG). The detectors were calibrated for different geometries with respect to energy, efficiency and resolution, using an Amersham mixed radionuclide standards. This calibration was made by measuring radioactive Amerasham mixed standard for six hours (Table 1). The samples were introduced to the gamma spectrometer and the spectra were accumulated for 36 hours. Fitzgerald peak software was used for spectrum collection saving and analysis. The background gamma-ray spectrum of the detection system was determined with an empty Marinelli beaker under identical conditions, and was subtracted from the spectra of each sample. Assume of activities of ^{214}Bi (19.9 minutes half-life) (609 KeV) and ^{214}Pb (28.8 minutes half-life) (352 keV) in equilibrium with their parents represent the ^{238}U activity by using the 609 keV peak (Hemby and Tynybekov, 2002; Alnour et al., 2012a and b). While ^{40}K was determined directly through (1460 keV). The certified reference material supplied by International Atomic Energy Agency (IAEA), was used as quality control sample and the results show good agreement between measured and certified values, relative error calculated was <10%.

Precision and accuracy are limited by the availability of material (up to100 g), counting time (12–48 hour), uncertainties in the calibration standards and detector background is calculated. Measuring time varies according to the sample type.

Table 1.Gamma energies, branching ratios and the half-lives of radionuclides used for gamma-system calibration

Nuclide	E(KeV)	half-life	Branching ratio (%)
^{241}Am	59.5	432.7 year	36.3
^{109}Cd	88	463 day	3.60
^{57}Co	122	271day	85.60
^{139}Ce	166	137.7 day	79.90
^{203}Hg	279	46.6 day	81.50
^{143}Sn	392	115 day	64.17
^{137}Cs	661.66	30 year	84.62
^{88}Y	898	106.61day	94.00
^{88}Y	1836	106.61day	99.35
^{60}Co	1173.24	1929 day	99.90
^{60}Co	1332.5	1929 day	99.98

Results and Discussion

Activity Concentration Levels

The results of activity concentrations (Bq/Kg) for ^{238}U and ^{40}K from investigated rock samples are given in Table 2 and 3.

^{238}U

The activity concentrations of ^{238}U were estimated assuming radioactive equilibrium in the ^{238}U—^{226}Rn—^{222}Rn—^{214}Pb—^{214}Bi decay series, which occurs in the vast majority of minerals (Attendorn and Bowen, 1997; Malczewski and Dziurowicz, 2015). It seems to be a reasonable assumption since ^{226}Ra is generally in approximate equilibrium with ^{238}U in many rocks (Eisenbud and Gesell, 1997). The activity concentration levels of ^{238}U from migmatite gneiss in Elobeid area ranged from 6.24 to 84.3 Bq./Kg. with an average

value of 39.7 Bq./Kg. (Table 2). The corresponding values were 30.3 Bq./Kg. to 73.3 Bq./Kg. with an average value of 52.5 Bq/Kg from micaschist (Table 3). The highest levels of activity concentrations of ^{238}U were refer to the mimatite gneiss samples collected from Jebel Abu Uroag samples (MU_2 and MU_3) and Jebel Kurbaj sample MR_1. However, the migmatite gneisis from Jebel Kordofan samples MK_4 and Jebel Kurbaj MR_5 exhibit lowest activity concentration levels amongst other samples. The activity concentrations are compared with the average activity concentrations of ^{238}U in the continental crust i.e 36 Bq./Kg. (Eisenbud and Gesell, 1997; UNSCEAR 2000). The migmatite gneiss from Jebel Kordofan sample MK_6 and MK_9 and Jebel Abu Uroag sample MU_1 display activity concentration levels clearly comparable to the activity concentration levels of the average value of the continental crust.

Table 2.Activity concentration of natural radionuclide 238U and 40K and concentrations of K and U from Migmatite gneisses in Elobeid City

Sample No	^{238}U (Bq/Kg)	^{40}K (Bq/Kg)	U (ppm)	K (Wt %)
MK_4	6.24	2196	0.50	7.23
MK_6	34.8	1018	2.80	3.36
MK_9	38.7	478	3.11	0.92
MU_1	27.0	881	5.10	2.90
MU_2	63.4	2389	2.17	7.87
MU_3	84.3	595	6.78	1.96
MR_1	55.8	1224	4.49	4.03
MR_5	7.65	3438	0.16	11.3
Mean	39.7	1502	3.14	4.95

Table 3.Activity concentration of Natural radionuclide 238U and 40K and concentrations of K and U from Micaschist in Elobeid City

Sample No	^{238}U (Bq/Kg)	^{40}K (Bq/Kg)	U (ppm)	K (Wt %)
MK_2	30.3	1315	2.44	4.33
MU_{4a}	40.6	633	3.27	2.09
MU_{4b}	65.9	631	5.30	2.08
MR_3	73.3	659	5.90	2.17
Mean	52.5	809	4.23	2.67

The micaschist samples from Jebel Kordofan sample (MK_2) and Jebel Abu Uroag sample (MU_{4a}), display activity concentration levels in the range of average activity concentrations of continental crust i.e 36 Bq/Kg, reported by Eisenbud and Gesell, (1997). Noticeably, the samples MU_{4b} from Jebel Abu Uroag and MR_3 from Jebel Kurbaj show the highest values. These values are slightly higher than values of normal radiation background worldwide, which is estimated for ^{238}U as 25 Bg/Kg (UNSCEAR, 2000).

Noted that, the activity concentration levels of ^{238}U from the micashist samples measured in this study is generally higher than the activity values for mimatite gneiss (Table 2 and 3). As discussed above, the bulk compositions of the rock forming minerals are the main factor that influences the activity concentrations levels in the rocks. According to Faure (1986), ^{238}U-rich minerals are much more abundant in felsic rocks than in mafic ones. This can be explained by the incompatibility of both U during partial melting and fractional crystallization processes, Thus, leading the remaining of U in the melt to incorporate in minerals of felsic rocks. Furthermore, the origin of the rock forming minerals such as clay minerals also plays a key role to its content in ^{238}U (Glover et al., 2014). The basement rocks from the study area is formed mainly from sedimentary origin and therefore is comprised mainly of clay minerals, however, the micashist samples are more enriched in clay minerals relative to migmatite gneisses. In this case, the high activity concentration of ^{238}U from micashist samples can be referred to the high contents of clay minerals.

^{40}K

The measured activity concentration levels of ^{40}K ranged from 278 to 3438 Bq./Kg. with an average value of 1502 Bq./Kg. in gneisses and migmatite, and about 631 to 1315 Bq./Kg. with an average value of 809 Bq./Kg. in micaschist that collected from around Elobeid City (Table 2 and 3). Noted, the activity concentration levels of ^{40}K are compared with the average activity concentrations of the continental crust i.e. 850 Bq./Kg. (Eisenbud and Gesell, 1997) and the worldwide average value reported in the areas of normal radiation background which is 400 Bq./kg. (UNSCEAR, 2000). The results showed that some samples are characterized by very high values of ^{40}K activity concentrations. The highest levels of ^{40}K activity concentrations were noted in gneisses and migmatite from Jebel Kordofan samples (MK_4 and MK_6), Jebel Abu Uroag sample (MU_2) and Jebel Kurbaj samples (MR_1 and MR_5). This is caused by the large amount of potassium feldspar minerals (Dziedzicowa et al., 1981). Nevertheless, the gneisses and migmatite from Jebel Abu Uroag sample MU_1 display activity concentration levels clearly comparable to the activity concentration levels of continental crust. The lowest values of ^{40}K activity concentration levels (below the average of continental crust) were measured in gneisses and migmatite from Jebel Abu Uroag sample MU_3 and Jebel Kordofan sample MK_9 (Table 2). In contrast, it can be seen that the measured ^{40}K activity concentrations associated with micaschist samples did not differ much, expect one sample (MK_2) (Table 3). The micaschist from Jebel Kordofan samples MK_2 showed high

levels of activity concentrations, while the measurements in the Jebel Abu Uroag samples MU_{4a} and MU_{4b} and Jebel Kurbaj MR_3 display the lowest activity concentrations levels (below the level of the average continental crust). Noticeably, the lower values of ^{40}K activity concentration levels from both gneisses and migmatite and micaschist are much higher than the worldwide average reported in the areas of normal radiation background (UNSCEAR, 2000).

A common feature in any environmental radiation measurements is the considerable variation in the rock radioactivity with rock type depending on the mineral compositions (Florou and Kritidis, 1992; Anjos et al., 2005). Higher radiation levels are associated with felsic minerals, and lower levels with dark minerals. The acidic rocks can present high concentrations of felsic minerals content compared with basic rocks. Thus, more acidic rocks generally exhibit high concentrations of the radionuclides with respect to the basic rocks (Larsen and Gottfried; 1960; UNSCEAR Report, 1993). The gneisses and migmatite have high contents of felsic minerals and are very poor in dark minerals relative to the micaschist (Glover et al., 2014). Therefore, the higher values of activity concentration levels of ^{40}K in migmatite gneisses can be explained in relation to their mineral compositions.

Geochemical Behavior of Uranium and Potassium

Naturally uranium occurrence is widespread in the environment and consists of three isotopes, all of which are radioactive: ^{238}U (99.2739%), ^{235}U (0.7025%) and ^{234}U (0.0057%). The ratio of ^{235}U to ^{238}U is less than 1%; therefore the contribution of ^{235}U to the environmental amount is very small. ^{234}U is a decay product of the ^{238}U series (El-Dine et al., 2001). Potassium has 24 known isotopes three of which occur naturally: ^{39}K (93.3%), ^{40}K (0.0117%) and ^{41}K (6.7%). Potassium (K) is a major constituent of many rock forming minerals (K-feldspars; orthoclase, microcline), and is enriched in acidic igneous rocks relative to basic ones. Potassium is majorly produced in the earth's crust by potassic feldspars (e.g. orthoclase of approximately 13%) and biotite and muscovite micas–of about 8% (Kearey et al. 2002).

In this study, the the concentrations of ^{238}U (ppm) and ^{40}K (%) and the activity concentrations, were calculated using conversion factors given by International Atomic Energy Agency (IEAE, 1989),. The values were as follows 1 Bq./kg. = 0.003296 %K and 1 Bq./kg. = 0.08045 ppm U. The results of these calculations are given in Table 2 and 3. Potassium concentrations in a wide variety of rock types were estimated from approximately 0.1 to 3.5%. The concentration of K investigated from migmatite gneisis in J. Kordofan sample MK_6 show normal values of K (3.36%) which are very close to the highest values noted to gneisses worldwide (3.82%) (Malczewski et al., 2004), and it is situated in the range of potassium abundance in acidic rocks such as granite, i.e. 3.67–4.45% (Van Schmus, 1995). However, the mimatite gneiss in J. Kordofan sample MK_4 and J. Abu Uroag sample MU_1 show highest value of K concentration 7.23 and 7.87%, respectively. The increase in ^{40}K radionuclide along the samples MK_4 and MU_1 could probably be due to high contents of the potassic feldspar and other radioactive feldspar minerals. On the other hand, the lowest K concentrations were documented from J. Kordofan sample MK_9 (0.91%) and Jebel Abu Uroag samples MU_2 (2.90%) and MU_3 (1.95%). The micaschist from J.Kordofan sample MK_2 exhibit high concentrations of 4.33, wich are consistent with those reported for typical micaschist (Van Schmus, 1995; Malczewski et al., 2004), while the lowest values of are observed in J. Abu Uroag samples MU_{4a} (2.08) and MU_{4b} (2.08).

The lowest concentration of U (ppm) was measured from migmatite gneisis. Samples MK_4 (0.50), MK_6 (2.80) and MU_1 (2.17), and from micaschist sample MK_2 (2.44). While, the highest concentration of U ppm were measured from mimatite gneiss samples MK_9 (3.12), MU_2 (5.10) and MU_3 (6.78) and from micaschist samples MU_{4a} (3.27) and MU_{4b} (5.36). On the average, the mimatite gneiss and micaschist samples show higher elemental concentrations of ^{40}K and ^{238}U above the average crustal concentrations of K 2–2.5% and U 2–3 ppm, respectively (IAEA, 2003). This increase may suggest high enrichment of radioactive minerals such as K-feldspar in the gneissic rocks and U-bearing minerals.

In general the felsic rocks (the most feldspar-rich) have larger U and K concentrations. However, in these measurements, the highest measured levels of ^{238}U (ppm) and ^{238}U (Bq./kg.) concentrations in the investigated rock samples are associated with the samples that have relatively low ^{40}K (%) (Table 2 and 3). As seen in Figure 2(a-d), there is a strong negative correlation between the activity concentration levels of ^{40}K and ^{238}U concentrations with a correlation coefficient of 0.71 for ^{40}K (%) and ^{238}U (ppm) in the investigated rocks. This strong negative correlation indicates different geochemical behavior for ^{238}U and ^{40}K in the primary geochemical environment. ^{238}U and ^{40}K have different radii, oxidation states and are electropositive elements that have strong ionic bonds. The dominant U valence states that are stable in most geologic environments are U^{+4} (NRC, 1999). U has the possibility to be in either U^{+5} or U^{+6} state. The U^{+5} state of like $Th^{+3}$is not expected under geologic conditions (Seaborg and Katz, 1954). Under reducing conditions, U is stable and difficult to migrate. However, their high valence compounds and complexes have low melting points, small densities, and are water-soluble. Therefore, under oxidative conditions, they are prone to migration in the environment (Xuezhao and Ali 1998). However, ^{40}K occurs in the K^{+1} state in the primary geochemical environments. Therefore, the nuclear charge

and atomic radii can be assigned to determine how closely the centers of atoms or ions actually approach each other in solid substances.

Acknowledgement

The laboratory analyses of this work have been developed in Sudan Atomic Energy Commission (SAEC). The teams of SAEC are greatly appreciated.

Conclusion

Natural radioactivity levels and elemental concentration of ^{238}U and ^{40}K in the basement rocks from Elobeid area have been measured using in situ gamma-ray spectrometry system and three exposure rates have been estimated. For ^{238}U, the highest activity concentrations were recorded in micaschist, whereas in the migmatite gneiss showed the lowest values. The coefficient of correlation found between ^{40}K and ^{238}U indicate a negative relationship. However, the highest concentration values of ^{40}K were found in mimatite gneiss rocks, whereas the lowest values were found in micaschist.

The average activity concentrations of these radionuclides are higher than the world- wide average values for the areas of normal radiation back-ground reported by UNSCEAR (2000), except the ^{238}U in the mimatite gneiss wich is consistant with the world- wide average values.

References

1. Alnour AI, Ibrahim N, Hossain I. Concentration of ^{214}Pb, $^{214}Biin$ ^{238}U series and ^{208}Tl, $^{228}Acin$ ^{232}Th series in granite rock in (Kadugli) Sudan. *Indian J Pure Appl Phys* 2012a; 50: 285-682.
2. Alnour AI, Wagiran H, Ibrahim N et al. Natural radioactivity measurements in the granite reock of quarrysites, Johor, Malaysia. *Radiat Phys Chem* 2012b; 81: 1842-1847.
3. Anjos RM, Veiga R, Soares T et al. Natural radionuclide distribution in Brazilian commercial granites. *Radiation Measurements* 2005; 39: 245-253.
4. Arafa W. Specific activity and hazard of granite samples collected from the Eastern desert of Egypt. *J Environ Radioact* 2004; 75: 315-327.
5. Eisenbud M, Gesell T. Environmental Radioactivity from Natural, Industrial and Military Sources. Acad. press, San Diego, CApp. 1997; 134-200.
6. El-Mageed AI, El-Kamel AH, Abbady A et al. Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environments of Juban town in Yemen Radiation. *Physics and Chemistry* 2011; 80: 710-715.
7. El-Dine W, El-Shershaby A, Ahmed F et al. Measurement of radioactivity and radon exhalation rate in different kinds of marbles and granites. *Appl Radiat Isot* 2001; 55: 853-860.
8. Faure G. Principles of Isotope Geology, second ed. John Wiley & Sons, London. 1986.
9. Florou H, Kritidis P. Gamma radiation measurements and dose rate in the coastal areas ofa volcanic island, Aegean Sea, Greece. *Radiat Prot Dosim* 1992; 45: (1/4): 277-279.
10. Glover TT, Akiti, Osae S. Natural radioactivity in some geological formation in the Accra Plains. *Elixir Geoscience* 2014; 76: 28144-28150.
11. Hamby DM, Tynybekov AK. Uranium, thorium and potassium in soils along the shore of the Lake Issyk-Kyol in the Kyrghyz Republic. *Environ Monitor Assess* 2002; 73: 01-108.
12. Ibrahiem NM, Abd El Ghani, Shawky AH et al. Measurement of radioactivity levels in soil in Nile Delta and Middle Egypt. *Health Phys* 1993; 4: 620-627.
13. International Atomic Energy Agency (IAEA). Construction and Use of Calibra- tion Facilities for Radiometric Field Equipment. Technical Reports Series no. 309, IAEA, Vienna. 1989.
14. International Atomic Energy Agency (IAEA). Radiation protection and the management of radioactive waste in the oil and gas industry. *International Atomic Energy Agency* 2003; 173.
15. Larsen ES, Gottfried D. Uranium and thorium in selected sites of igneous rocks. *Am J Sci* 1960; 258A: 151-169.
16. Kearey P, Brooks M, Hill I. An Introduction to Geophysical Exploration, 3rd ed., Oxford: Blackwell Science. 2002; 262.
17. Malczewski D, Teper L, Dorda J. Assessment of natural and anthropogenic radioactivity levels in rocks and soils in the environs of S ´wierado´w Zdro´j in Sudetes, Poland, by in situ gamma-ray spectrometry. *J Environ Radioact* 2004; 73: 233-245.
18. Malczewski D, Dziurowicz M. ^{222}Rn and ^{220}Rn emanations as a function of the absorbed a-doses from select metamict minerals. *Am Miner* 2015; 100: 1378-1385.
19. Maxwell O, Wagiran H, Ibrahim N et al. Comparison of activity concentration of ^{238}U, ^{232}Th and ^{40}K in different Layers of subsurface Structures in Dei-Deiand Kubwa, Abuja, north central Nigeria Omeje Radiation Physics and Chemistry. 2013; 91: 70-80.
20. Mukhtar A. Environmental Study for Radionuclides at Miri Lake. Ph.D. Thesis, Faculty of Science, Department of Physics, University of Khartoum. 2003.
21. Mireles F, Davila JI, Quirino LL et al. Natural soil gamma radioactivity levels and resultant population dose in the cities of Zacatecas and Guadalupe, Zacatecas, Mexico. *Health Phys* 2003; 84(3): 368-372.
22. NRC. Evaluation of Guidelines for exposures to Technologically Enhanced Naturally Occurring Radioactive Materials, National Research Council , Washington, DC. 1999.

23. Quindos LS, Fernandez PL, Soto J et al. Natural radioactivity in Spanish soils. *Health Phys* 1994; 66(2): 194-200.
24. Sam AK, Holm E. The natural radioactivity in phosphate deposits from Sudan. *Science and Environment* 1995; 162: 173-178.
25. Sam AK. Assessment of Terrestrial Gamma Radiation in Sudan. *Radiation Protection Dosimetry* 1997; 71: 141-145.
26. Seaborg GT, Katz JJ. The Actinide Elements, National Nuclear Energy Series, MaGraw-Hill,N.Y. 1954.
27. Tennisseen AC. Nature of earth materials. Printice-Hall, NJ07632: 1994; 333-334.
28. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Source and affects of ionizing radiation. Report to General Assembly with Scientific Annexes, United Nations, New York. 1993.
29. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Exposure from natural sources of radiation. United Nations, New York. 1993.
30. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Source and affects of ionizing radiation. Report to General Assembly with Scientific Annexes, United Nations, New York. 2000.
31. U.S. Environmental Protection Agency Diffuse NORM Waste Characterization and Preliminary Risk Assessment, Washington, DC, U.S. EPA, RAE-9232/1-2, Draft Report. 1993.
32. U.S. Nuclear Regulatory Commission, NRC. Health Risk of Radon and Other Internally Deposited Alpha-Emitters. Academia press, Washington, DC, NRC Report BEIR IV. 1988
33. Vail JR. Outline of the geology of the Nuba Mountains and Vicinity, Southern Kordofan Province, Sudan. 1973.
34. Vail JR. Outline of the geology and mineral deposit of the Democratic Republic of Sudan and adjacent areas. Overseas Geology and Mineral Resources. 1978; 49.
35. Van Schmus WR. Natural radioactivity of the Crust and Mantle. in: Ahrens, T.J. (Ed.), Global Earth Physics: A Handbook of Physical Constants. American Geophysical Union, AGU Reference Shelf 1, 1995; 283-291.
36. Xinwei L, Xiaolon Z. Natural radioactivity measurements in Rock samples of Chihua Mountain National Geological Park. *China Radiat Prot Dosim* 2008; 128: 77-82.
37. Xuezhao B, Ali Z. Geochemistry of U and Th and its Influence on the Origin and Evolution of the Earth's Crust and the Biological Evolution Acta Petrologica et Mineralogica. 1998; 17(2): 160-172.