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RESEARCH ARTICLE

Soil Radioactivity and Elemental Characterization of the Area Proposed for the First Nuclear Power Plant at Red Sea State, Eastern Sudan

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Abstract:

This paper describes the results of a radiological survey for the purpose of establishing a basic database of radioactive elements in soil from one of the regions proposed for the establishment of a nuclear power plant in Sudan. Herein, we focus on analyzing radioactivity indices in 105 locations. As such, the data provide the basis for a reference map to detect emissions or a significant increase in radiation levels in the region. Soil radioactivity were measured by a high-precision gamma ray spectrometer using a highly pure Germanium detector encased in a copper lined lead shield located in a low background environment. Ambient dose (D_{air}) at each location was calculated based on Ra, Th and K concentrations in soils. The radioactivity levels in the soil of the area does not poses any risks, as evidenced by the values of the external hazard (H_{ex}), representative level ($I\gamma$), radium equivalent (Ra_{eq}), and Annual Gonadal Dose Equivalent (AGDE) indices (all values were less than recommended levels). Relationship between U-238 decay series and 232Th decay series in soil samples was observed positive correlations have also been observed between other metals Cr and Au (+0.82), Br and Nb (+0.84), Hf and Sb (+0.75). On the other hand, there are moderate positive correlation Cu and Au (+0.57), Zn and W(+0.61, Au and Ag(+0.63), Sb and Cr(+0.58), Rb and V(+0.55), Rb and Ni (+0.56), but weak correlation was noted between radioactive material and non-radioactive elements.

Keywords: Soil radioactivity, Radiation indices, Ambient dose, Sudan.

Introduction

The aim of this paper is to assess the radioactivity of soil from an area proposed for a nuclear power plant, based on master plan of the Ministry of Water Resources, Irrigation and Electricity, Sudan. The preliminary surveys to determine the site of the first nuclear power plant had been completed and the country needs to build this plant to fill the gap in power generation. As generally known from various studies, we live in a world in which radiation is present everywhere, coming either from natural or artificial sources and humans are always exposed to radiation from the natural sources. The most known are Uranium (^{238}U), Thorium (^{232}Th), and their daughters in addition to Potassium (^{40}K). The presence of the artificial radionuclides may be from nuclear activities such as accidents resulting from nuclear power plants, tests of some nuclear weapons and others. In the framework of the nuclear plant for electricity generation in Sudan this research work for environmental survey areas that have been nominated for the station's work as the basic criteria for the selection of site for the nuclear power station (Eastern and Red sea region). The concentration of radioactivity in soil is a logical indicator of the distribution of radioactivity in the target area and it can provide a strong data baseline to construct radioactivity and radiation map for the selected region. The outcome of this research can be addition and/or reference for other studies before and after establishing the first Nuclear Power Plant (NPP) in Sudan.

Many studies in this field are focusing on the measurements of radioactivity concentrations to determine the areas of high levels and correlation between radioactivity in soil and non-radioactivity in soil and geological structure of areas under study (Kannan et. Al, 2002; Matiullah et al, 2004; El-Arabi, 2005; Sahoo et al, 2011; Rashed-Nizam et al, 2015; Idriss et al, 2016; Nkuba et al, 2017; Ribeiro et al 2018). In Sudan, there are some previous research conducted to study the radioactivity concentrations of ^{238}U, ^{232}Th and ^{40}K in various environmental compartments (Osman et. al, 2008; Salih et al, 2011; Iddris et al, 2013; Fadol et al, 2016; Idriss et al, 2016; Abalhamid et al, 2017; and Idriss et. al 2018), as a part of environmental radiation monitoring program. The results of these investigations showed significant variations among different regions. That was attributed to many parameters such as geology and deformation of the study area and how the differences in the geological structure, lithology and climate parameters... etc. The main objectives of the present study are producing radioactivity data for the Red Sea State, eastern Sudan.

Materials and methods

The study area

The area under consideration (Figure 1) is located between latitude 20^0 N and longitude 34^0 E and between latitude 18°N and longitude 38° E. The study area located within a transition climate zone between the red sea coastal region and arid/semi-arid northern Sudan region. Based on the investigation conducted by Sudan metrological Authority-Drought monitoring center, the study area located on the middle of the Red sea winter zone where the mean November rainfall contour given about 25 mm and it increases in the east coastal region and decreases towards west. The study area presents a part of the Gebeit terrain that is created during the Pan-African event. The geology comprises high-grade gneisses, volcano sedimentary sequences metamorphosed in the greenschist facies, all intruded by syn and syn-to-late orogenic calc-alkaline intrusive and post-orogenic alkaline bimodal gabbro granite complexes (Babikir 2006). The shoreline is, geologically, characterized by Cenozoic siliciclastic and shallow marine rift-related sedimentary structures. Pliocene-Pleistocene is represented by the thick older gravel unit and the emergent linear reef terraces. The previous studies have constantly indicated that ^{226}Ra, ^{232}Th and ^{40}Kconcentrations in soil vary according to geological formation and characteristics of soil of the region. Based on geological map, these areas are characterized by sedimentary, volcanogenic sediments and Nubian sandstone.

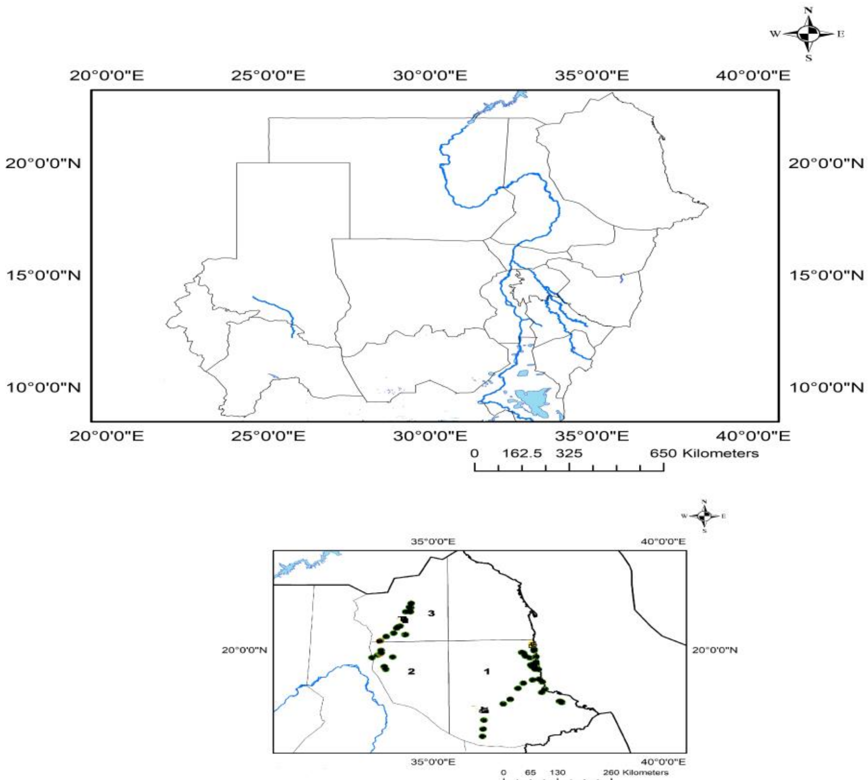

Figure 1 Map of the Red Sea state showing the 105 sampling sites located at irregular intervals as the samples were collected during field surveys of the area.

The wind differs in winter from north to northeast with average speed of 7 miles/hour and it increases during April, May and June with sandstorms. Geology of the investigated area characterize by a complex consisting of highly deformed volcanic and volcanogenic sediments, Quaternary (to Tertiary) unconsolidated sedimentary, cretaceous Nubian sand stone and other formations.

The Sudanese coastal plain is dominated by limestone that, almost, covers all the area as shown in Figure 2.

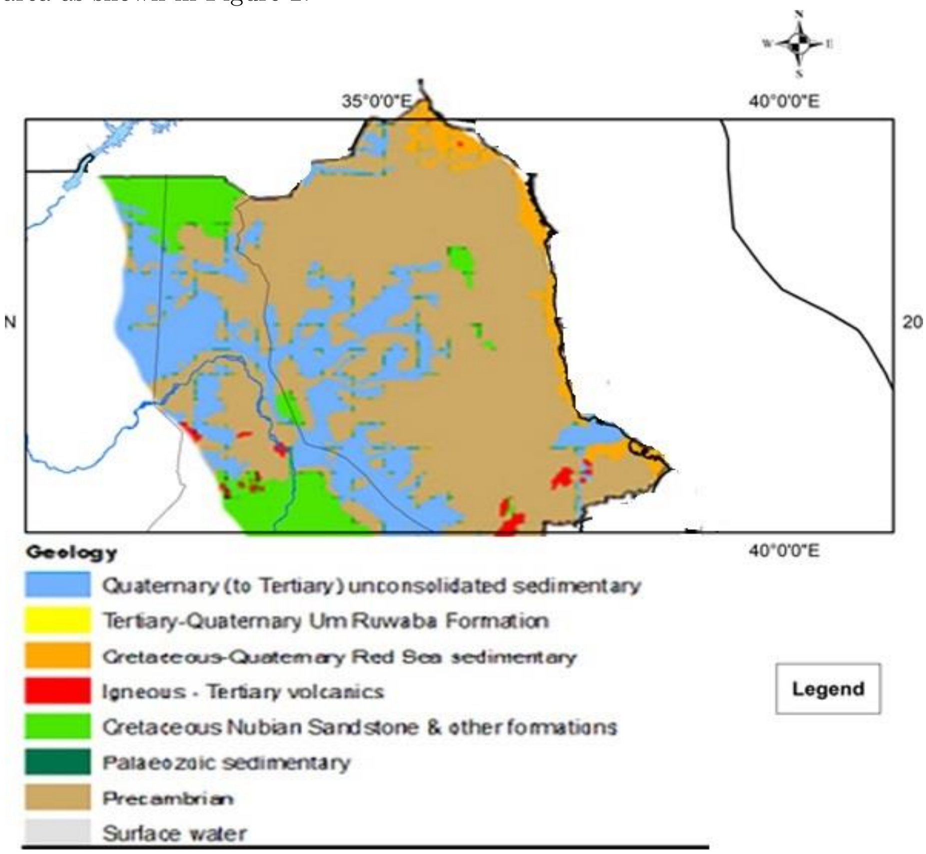

Figure 2 Geological map of the study area, as extracted from Sudan geological map (Babiker 2006).

Extracted part from the geological map for the study area (Red sea region)

Sample collecting and preparing

From different areas of Red sea region 105 soil samples were taken using core sampler up to depth of about 20 cm and the location of each sample recorded using a GPS device. The amount of collected sample is around 1 kg and then samples homogenized and sent to the laboratory where further preparation taken place (crushing into a fine powder and sieved through a sieve). Afterward the samples were sealed in 500-ml plastic Marinelli beakers for approximately 4 weeks to allow radon (half-life 3.8 days) and its short-lived decay daughters to reach secular equilibrium with the long-lived parents. Subsamples were separated for elemental analyses (non-radioactive).

Radioactivity measurements

Radioactivity measurements was performed using Gamma Spectrometer based on HPGe detector (GCD-30 185X with lead shield (S/N: 2293-16)). The study of non-radioactive variables was conducted using X-RAY Fluorescence Spectrophotometer (Model – TT- SXRF1000), 100-240 VAC, 50/60 Hz, Spectrum acquisition time 10-1200sec, Range of detectable elements (Na to U).

Calculation of radiological hazard indices

Four hazard indices 'Absorbed Dose Rates, DR','Radium Equivalent Activity, Ra_{eq}', 'External Hazard Index, H_{ex}' and 'Gamma index, Iγ' were computed using equations 1-4 below (OECD-NEA 1979; UNSCEAR 1982; ECRP 1999; UNSCEAR 2000; UNSCEAR 2008; Khandaker et al. 2012; Adziz and Khoo, 2018):

$$D_R(nGyh^{-1}) = 0.462\,A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (1)$$

$$R_{aeq}\,(Bq.Kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (3)$$

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{4000} \quad (4)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively

Elemental measurements

The collected samples were analyzed to measure the concentration level ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs using HPGe and for major elements (U, Sn, Cd, Pb, Zn, Au and Ag) using XRF and Atomic absorption and all analyzes were conducted under the standard conditions. The samples were more crushed to fine powder (to unified the size of the soil granules).

Results and discussions

The radioactivity level of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in Red Sea state soil samples and their descriptive statistics are given in Table (1) and it shows that the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were ranged from 7-89, 6-91, 24-1100 and 0.01-3.0 respectively in term of Bq/kg.

The average magnitudes of the radionuclides follow the order ^{137}Cs $<^{226}Ra$ $<^{232}Th$ $<^{40}K$ $<$ as displayed in figure (8) and the large differences in the radioactivity level of the measured radionuclides are attributed to their physico-geological, geochemical characteristic and behavior in soil environment. Usually, activity concentrations of ^{238}U, ^{232}Th daughters are associated with heavy minerals, and ^{40}K activity concentrations with clay minerals. On the other hand,

^{210}Pb is transported from terrestrial regions into the atmosphere via ^{222}Rn diffusion and during rainfalls; it may be accumulated in closed ecosystems as a result of scavenging from raindrops. (Risk). In this study, the average value of ^{226}R, ^{232}Th, ^{40}K are lower than the global average value. The global average for226Raobtained by (UNSCEAR, 2000) 35Bq/kg and 40 Bq/kg by (UNSCEAR, 1988 and 1993). In this study, the average value of 226Ra was obtained 43 Bq/kg, which is closed to the global value.

The global average for the activity concentration of ^{232}Th was 40 Bq/kg (UNSCEAR, 2000) and the average concentration from the result was 36 Bq/kg which is also same order of magniyutde as the allowable global average. Comparing the global values obtained for ^{40}K from the result, the average is 374 Bq/kg which is less than the global average 580 Bq/Kg obtained by(UNSCEAR; 1988 and 1993) and 400 Bq/kg by (UNSCEAR, 2000). The higher activity of ^{226}Ra, ^{232}Th and ^{40}K were observed in locations at arid area whereas the lower level of such radionuclides were recorded in location near red sea. ^{137}Cs activity level in the current study showed very low levels in the most samples, this implies the area has low level of contamination. The principal source of ^{137}Cs released to the environment to date has been the atmospheric testing of nuclear weapons and the accidental release from the routine operation of nuclear reactors. Our results of soil radioactivity level compared with the results of similar studies in the different countries around the world and a summary of the results are given in Table 1.

Table 1: Statistical parameter for radioactivity concentration of ^{226}Ra, ^{232}Th,^{40}K and ^{137}C in soil samples around different areas in Red sea regions

Statistical parameter	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Mean	36	43	374	0.05
Min	6.0	7.0	24.0	0.01
Max	91	89	1100	3.0
SD	12	13	263	0.08

The obtained values can be classified as low radioactivity level and comparable to values from other similar studies.

Radiation indices were calculated from the radioactivity of ^{226}Ra, ^{232}Th and ^{40}K in soil. Namely, these are: radiation absorbed dose in air (D_R), radium equivalent (R_{aeq}), external hazard index (H_{ex}) and Iγ. As shown in Table 2, the values falls well below the level of global average and recommended levels.

Table 2: Average D_R, R_{aeq}, H_{ex}, and Iγ for the 3 different areas in Red sea regions (as show in Fig 1)

Area	DR (nGy/h)	Raeq (Ba/Kg)	H_{ex}	Gamma index Iγ
1	43	153	0.1	0.2
2	48	147	0.3	0.2
3	78	177	0.5	0.3
Total average	57	171	0.45	0.33

The average values of D_R was 57 nGy/h similar the global average value, 171 Bq/Kg for R_{aeq} less than the recommended limit 370 Bq/kg (UNSCEAR, 2000). The External Hazard Index 0.45 (H_{ex}) and Gamma Index 0.33 ($I\gamma$) were less than unity that means low radiation hazards for human in the region.

Correlation test has been done to estimate the relationships between pairs of variables via computation of the linear Pearson correlation coefficient. The results of correlation analysis between all the measured radionuclides in soil samples from Red Sea state depicted in Table 3. The correlation matrix of radionuclides has explained a positive correlation between the variables ^{232}Th and ^{40}K, ^{226}Ra and ^{40}K.

Table 3: Correlation results among all measured variables (Bold values represent the correlation is significant at p-level < 0.05).

	^{226}Ra	^{232}Th	^{40}K	Rb	Y	Br	Sr	Hf	Sb	Cr	V	Nb	Ni	Te	Pd	Sn
^{226}Ra	1															
^{232}Th	**0.69**	1.00														
^{40}K	**0.55**	0.33	1.00													
Rb	0.08	0.03	0.11	1.00												
Y	0.29	0.33	0.13	0.25	1.00											
Br	0.26	0.27	0.08	-0.14	0.21	1.00										
Sr	-0.21	-0.06	-0.08	-0.12	-0.03	0.02	1.00									
Hf	-0.13	-0.14	-0.11	-0.38	-0.13	0.06	0.25	1.00								
Sb	0.04	0.07	-0.25	-0.46	0.05	0.69	0.23	**0.75**	1.00							
Cr	0.09	0.04	0.01	0.17	0.24	0.36	0.10	0.47	**0.58**	1.00						
V	-0.16	-0.15	-0.01	**0.55**	0.21	-0.77	-0.07	-0.21	-0.66	-0.05	1.00					
Nb	0.26	0.24	0.03	-0.20	0.18	**0.84**	0.13	0.45	0.82	0.49	-0.71	1.00				
Ni	0.08	0.11	0.07	**0.56**	0.60	0.38	0.00	0.01	0.21	**0.67**	0.25	0.31	1.00			
Te	-0.25	-0.20	-0.10	-0.27	-0.34	-0.07	0.08	-0.08	0.09	0.15	-0.09	-0.28	-0.11	1.00		
Pd	0.25	0.13	0.11	0.11	0.19	**0.68**	-0.11	-0.38	0.04	0.00	-0.43	0.38	0.31	-0.17	1.00	
Sn	0.23	0.13	0.01	0.03	-0.08	0.16	-0.02	-0.09	-0.15	0.00	-0.10	0.12	0.06	-0.04	0.36	1.00

	^{226}Ra	^{232}Th	^{40}K	Fe	Cu	Ca	Zn	Ti	Mn	Zr	Cd	Pb	Mo	Cr	W	Au	Ag
^{226}Ra	1.00																
^{232}Th	0.69	1.00															
^{40}K	0.55	0.33	1.00														
Fe	-0.07	-0.15	-0.03	1.00													
Cu	0.02	-0.05	-0.03	0.44	1.00												
Ca	-0.13	-0.07	-0.04	-0.22	-0.14	1.00											
Zn	0.21	0.21	0.01	0.20	0.14	-0.34	1.00										
Ti	0.02	0.10	0.02	0.09	-0.29	-0.07	0.40	1.00									
Mn	0.06	-0.06	0.01	0.28	0.06	-0.13	0.20	0.40	1.00								
Zr	0.12	0.12	0.11	0.17	-0.25	-0.12	0.47	0.92	0.43	1.00							
Cd	0.14	0.04	-0.07	0.24	-0.06	0.01	0.10	0.02	-0.05	-0.02	1.00						
Pb	-0.16	-0.14	0.00	0.48	-0.19	-0.02	0.08	0.63	0.37	**0.65**	-0.06	1.00					
Mo	0.01	0.20	0.03	-0.29	-0.24	-0.09	0.26	0.44	0.24	0.38	0.03	-0.03	1.00				
Cr	-0.09	-0.07	-0.06	0.21	0.52	-0.01	0.32	-0.41	-0.04	-0.30	-0.07	-0.30	0.02	1.00			
W	0.12	-0.02	0.09	0.27	0.11	-0.31	**0.61**	0.14	0.24	0.30	0.07	0.13	0.06	0.29	1.00		
Au	-0.17	-0.18	-0.12	0.41	**0.57**	-0.28	0.12	-0.34	0.01	-0.29	-0.11	-0.13	-0.13	**0.82**	0.14	1.00	
Ag	-0.14	-0.17	-0.09	0.18	0.36	-0.39	-0.44	-0.50	-0.17	-0.53	-0.11	-0.18	-0.35	0.21	-0.30	**0.63**	1.00

Correlation test has been conducted, with a view to measure the associations and strength of relationship between pairs of variables through calculation of the linear Pearson correlation coefficient. Table 3 presents the Pearson correlation coefficients between all the studied radioactive and non-radioactive variables. From the results obtained it was found that the correlation matrix of red sea state soil shows a cluster of high positive correlation between the variables ^{226}Ra and ^{232}Th (+0.69). This indicates the strong relationship between U-238 decay series and ^{232}Th decay series in soil samples with moderate positive correlations observed between ^{226}Ra and ^{40}K (+0.55). Strong positive correlations have also been found between other metals Cr and Au (+0.82), Br and Nb (+0.84), Hf and Sb (+0.75) and high positive correlations between Zr and Pb(+0.65), Ba and Pd(+0.68). On the other hand, there are moderate positive correlation Cu and Au (+0.57), Zn and W(+0.61) ,Au and Ag(+0.63) , Sb and Cr(+0.58), Rb and V(+0.55), Rb and Ni (+0.56), so no correlation was noted between radioactive material and non-radioactive materials.

In this study and the radioactivity concentrations in soil from different place attributed maily to the geological composition and formation and geographical distribution of soil types. As many samples were collected from living areas such as North Hya, Portsudan, Twahein, Saloom Port, Portsudan Port, Arows, Refinery, Bashair, Swaken, Towkar, between Alwadi and End Red sea (Bauda) the values of health indices showed low values compare to the international acceptable levels. Fig 3 presents results of calculated radioactivity and risk indices for these areas.

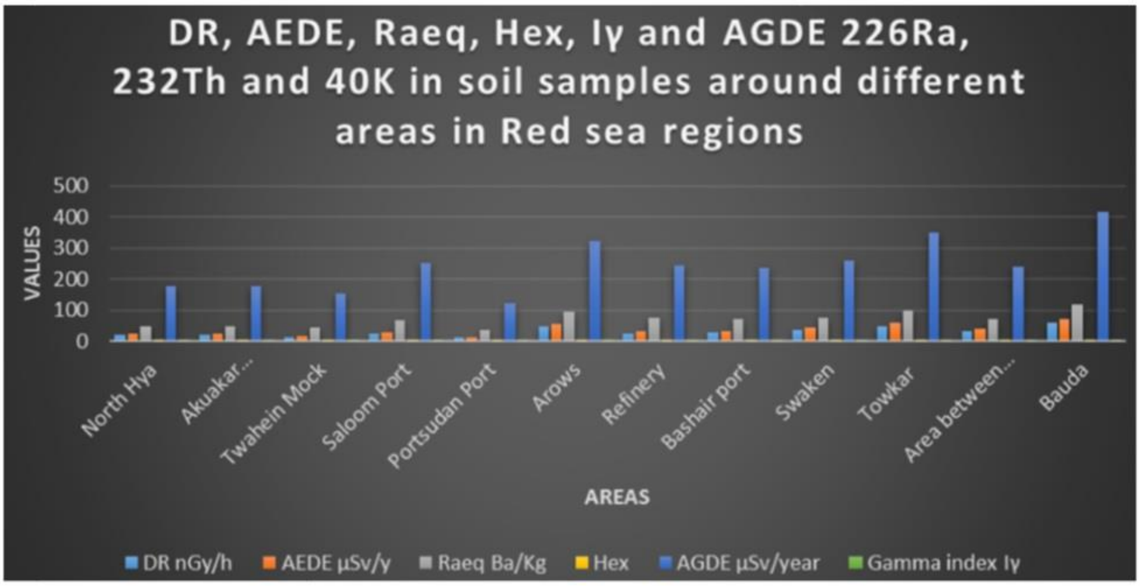

Figure 3 Results of calculated radioactivity and risk indices for these areas.

In table1, the maximum activity concentration of ^{137}Cs was 3 Bq/Kg and its very low in most of the sites, therefore no needs to worry about as there is no known nuclear activities in vicinity of the area. The justification of the presence of ^{137}Cs in the study areas due to one of the previous nuclear accidents. ^{137}Cs may be one of the consequences and the results of this accident which mixed up with air particles in the atmosphere and may be reached altitudes of 1000 m (Avery, 1996) or may be because of the passing of contaminated ships from different places. Moreover, winds directions and rainfall may have played an important role in the distribution of ^{137}Cs in soil in different areas in the world and this is why we still find ^{137}Cs in the samples of study areas. Note that the rainfall on the Red Sea region is very low but it can occur at any time of the year special in the winter session.

The comparison between our study and other studies may be useful to understand the distribution of radioactivity in different continents and may support global baseline data from Sudan as one of large area African country. The range of activity concentration of ^{226}Ra in the study areas is slightly less than the values for other countries in different continents. If we take Algeria and Egypt (Africa) as examples, we will find that the average of ^{226}Ra is around 5-180 Bq/Kg (Algeria) and 5-64 Bq/Kg (Egypt) and the mean is around 50 (Algeria) and 17 (Egypt) Bq/Kg. the same variance we will find in the average of the concentrations of ^{40}K and ^{232}Th, which is around 66-1150 Bq/Kg with the mean 370 Bq/Kg (Algeria), 29-650 Bq/Kg with the mean 320 Bq/Kg (Egypt) for 40K and 2-140 Bq/Kg with the mean 25 Bq/Kg (Algeria) and 2-96 Bq/Kg with the mean 18 Bq/kg (Egypt) for ^{232}Th. In the study areas, the average of 40K concentration is between 24-1100 Bq/Kg with the mean 374 Bq/Kg and 43 Bq/Kg for ^{232}Th with the mean 36 Bq/Kg and that means the low concentration in study areas.

Conclusion

The need for measurements of radionuclides in the soil came from the choice of the location of this study as one of the proposed locations for the establishment of the first nuclear plant to generate electricity in the country. From the perspective of environmental monitoring and the establishment of a basic database and a radiation map for this region, measurements were made of radioactivity, where the concentrations of each of the elements were calculated followed by estimation health risk indices. All indices were found to be less than the permissible limits proposed internationally. An attempt has also been made to study the association of radioactive elements with the non-radioactive and the geology of the region. It is found that the effect of each is not very significant, in relation to the natural distribution due to the factors of transport and movement of these elements over the years. Artificial radionuclides (^{137}Cs) concentration in soil was very low (<3 Bq/kg) indicating that the area is free of contamination.

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