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Investigations have been carried out for naturally occurring radionuclides in surface soils in selected regions of the Northern State of Sudan, in response to widely spread rumours of elevated levels of radioactivity causing higher than normal incidence of cancer in that area. Eighty surface soil samples were collected from different regions in the Northern State and their activity concentrations were measured by a high-purity germanium detector gamma spectrometer system. From the data obtained the mean values and standard deviations of the radionuclide activities were calculated. From the activity concentrations of 226Ra, 232Th and 40K radionuclides the external absorbed dose rate in air and the annual effective dose were calculated.The radium equivalent activity and the external hazard index were applied for estimating the radiation hazards of soil used as building material. The mean activity concentrations of 226Ra, 232Th and 40K in different regions of the Northern State were found to be 82.6 + 6.8, 26.0 + 2.9 and 726.4 + 72.0 Bq/kg, respectively.The average outdoor gamma absorbed dose rate in air at 1meter above ground was calculated as 84.6 + 7.1 nGy/h. The average annual effective dose equivalent for population in the regions under study was found to be 103.7 + 8.7 uSv/y. The external hazard index was found to be 0.48 + 0.04.

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Investigations of environmental radioactivity in the northern state of Sudan

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Abstract

Investigations have been carried out for naturally occurring radionuclides in surface soils in selected regions of the Northern State of Sudan, in response to widely spread rumours of elevated levels of radioactivity causing higher than normal incidence of cancer in that area. Eighty surface soil samples were collected from different regions in the Northern State and their activity concentrations were measured by a high-purity germanium detector gamma spectrometer system. From the data obtained the mean values and standard deviations of the radionuclide activities were calculated. From the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides the external absorbed dose rate in air and the annual effective dose were calculated.

The radium equivalent activity and the external hazard index were applied for estimating the radiation hazards of soil used as building material. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in different regions of the Northern State were found to be 82.6 + 6.8, 26.0 + 2.9 and 726.4 + 72.0 Bq/kg, respectively.

The average outdoor gamma absorbed dose rate in air at 1meter above ground was calculated as 84.6 + 7.1 nGy/h. The average annual effective dose equivalent for population in the regions under study was found to be 103.7 + 8.7 □Sv/y. The external hazard index was found to be 0.48 + 0.04.

Keywords: natural radioactivity levels; absorbed dose rate; annual effective dose equivalent.

1. Introduction

Investigations of environmental radioactivity from the naturally occurring radionuclides can be useful for the assessment of public dose rates as well as to keep reference data records. Studies of the environmental radioactivity due to the naturally occurring radionuclides have been widely carried out (1-6). Some relevant investigations have been performed in some regions of Sudan (7-8).

Terrestrial gamma radiation emitted from the naturally occurring radionuclides such as ^{238}U and ^{232}Th series and their decay products as well as ^{40}K, which exist in all ground formations, represent the main external source of irradiation to the human body(1). The present investigations were carried out in some of the inhabited regions of the Northern State of Sudan in

response to widely spread rumours of elevated levels of radioactivity causing higher than normal incidence of cancer among the population.

2. Materials and methods

The study area

Sudan is the largest country in area in Africa. Nearly one fifth of Sudan's area is within the Northern State, in the northwest corner bordering Egypt and Libya. The Northern State is mostly arid and almost entirely desert or semi-desert, except for the regions along the banks of the Nile. The human population of about one million is mainly found close to the banks of the Nile. Most of the population is involved in agriculture, which is dependent on irrigation. Date palms are almost continuous along both banks of the Nile. Other crops grown in the inhabited regions include wheat, fruits and vegetables.

The region under study lies between 18° 01' and 20° 06' north latitudes and 30° 12' and 31° 49' east longitudes. Dry northerly winds prevail throughout the year. Temperatures are high with large diurnal and annual variations. Dust storms are frequent during March and April. Rainfall is scarce, with some heavy showers every few years. Fig.1 shows the study area.

Samples collection and preparation

Eighty surface soil samples were collected from different locations in the Northern State. To avoid any surface contamination the soil samples were collected from 15 cm depth after cleaning the surface. Three samples, each weighing around 1 kg, were collected from each location and stored in clean polyethylene bags for analysis in the laboratory. In the laboratory the samples were air-dried, ground into fine powder, sieved at 2 mm mesh and stored in plastic containers, appropriately coded. 500g from each location was then packed in a plastic container (Marinelli beaker), sealed well and stored for 28 days before analysis. The containers were sealed to avoid any possibility of out gassing of ^{222}Rn and ^{220}Rn gases and stored for 28 days to allow the samples to attain radioactive equilibrium. Table 1 shows the codes and locations of the samples having the highest concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K. The samples with numbers from 1 to 26 come from the North Western area of the Northern State and the samples 37 to 86 from the South Eastern area.

Experimental measurements

The collected 80 soil samples were measured at the Experimental Nuclear Physics Unit/ Nuclear Research Centre/ Egypt Atomic Energy Authority for their ^{226}Ra, ^{232}Th and ^{40}K contents using a high-purity germanium (HPGe) detector gamma –ray spectromer system. A cylindrical lead-shield of 5cm thickness, which contains inner concentric thin cylinders of Cd, Cu, Fe and Al with a thickness of 2mm each, was used to shield the detector to reduce background. The system had a resolution of 2.35 keV for the 1.33 MeV gamma-peak of ^{60}Co. IAEA gamma standard sources of ^{22}Na, ^{57}Co, ^{60}Co, ^{133}Ba, ^{137}Cs and ^{152}Eu were used for the energy and efficiency calibration of the system in the geometry of the samples measurement in Marinelli beakers. After attainment of secular equilibrium each sample was counted for 6 hours and the spectra were saved in a computer for further analysis. Data analysis was performed taking into account sample

geometry, self-absorption in the sample and background. The obtained spectra

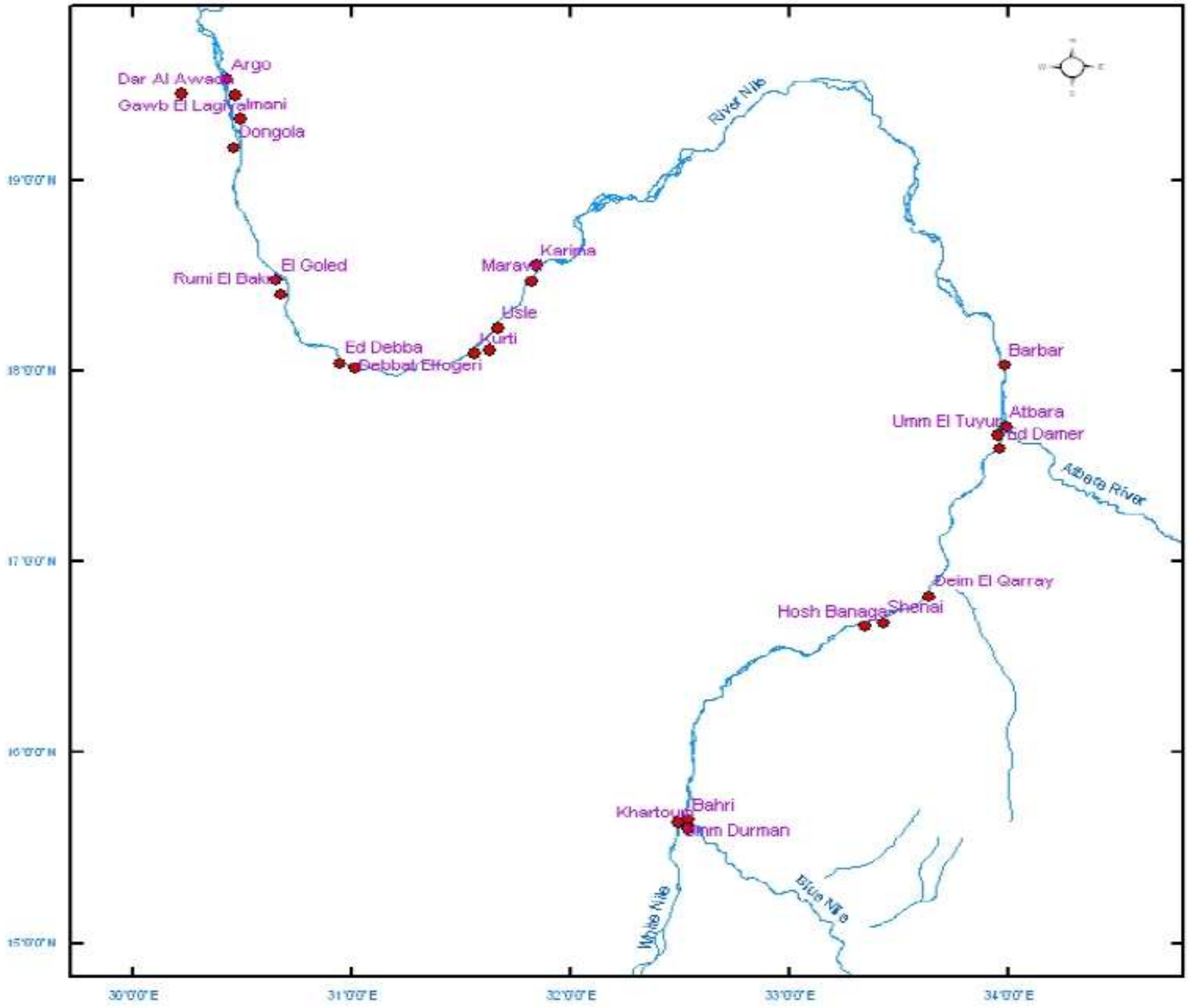

Figure 1 Main soil sampling locations in the Northern State of Sudan

Table 1: Some samples codes and locations.

Sample No.	Sample Code	Sample Location
1	1C	50 km north of Khartoum
2	3A	150 km north of Khartoum
3	4B	200 km north of Khartoum
4	5A	300 km north of Khartoum
5	6C	Dabbat Alfugaraa.
6	8B	North of Al Debba
7	10A	Albaja
8	16B	Sury
9	18B	Argo
10	21C	Alkhalasab
11	25B	Ab Nar
12	26B	Dar Alawda
13	33A	Silem University City for Girls
14	37A	Dongola – Algaab
15	40C	Al Goled Gibli
16	48B	Usle
17	58C	87 km from Amri Eljadida
18	59A	Almarowa
19	63C	Um El Tuyur
20	64B	Barbar
21	72B	Atbara
22	84C	Shendi
23	86C	Hosh Banaga

were then analyzed using Genie-2000 gamma analysis software. Since ^{238}U and

^{232}Th are not gamma-emitters, they were measured indirectly through the gamma–rays emitted from their daughters: ^{226}Ra, descendant of ^{238}U, was measured through ^{214} Pb (emitting gamma-rays of 295 and 352 keV), ^{232}Th through ^{212}Pb (emitting 239 keV gamma-rays). ^{40}K was measured directly from the emitted gamma-ray of 1461 keV. The system was calibrated for energy and efficiency on regular basis. The background was measured every week under the same conditions of sample measurement. The activity concentration of each radionuclide was finally measured in Bq/kg. These data were used for calculation of some radiological parameters to estimate the environmental impacts of the radionuclides.

3. Results and discussion

The measured activity concentrations of soil samples from 80 locations in the area under investigation gave activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the range 10-192, 6-90 and 152-2351 Bq /kg, with mean values of 82.6 ± 6.8, 26.0 ± 2.9 and 726.4 ± 72.0 Bq/kg, respectively.

The worldwide average concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil samples were reported as 30, 35 and 370 Bq/kg, respectively (UNSCEAR, 2000). The measured average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected from regions in the Northern State of Sudan were slightly higher than the world average values. Figures 2 and 3 illustrate the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K at the samples locations having highest concentrations.

The air absorbed gamma radiation dose rate D (nGy/h) at 1m height above the ground for the population living in the studied area was calculated using the following equation [8]:

$$D = 0.461A_{Ra} + 0.623A_{Th} + 0.0414A_K \quad (1)$$

where A_{Ra}, A_{Th} and A_K are the average activity concentrations in Bq/kg of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The outdoor gamma absorbed dose rates in air at 1 meter above ground for all 80 soil samples ranged from 10.3 to 216.2 nGy/h, with a mean value of 84.6 ± 7.1 nGy/h. This is higher than the worldwide median value of 51 nGy/h[2]. Figures 4 and 5 show the calculated average outdoor gamma absorbed dose rates in air at 1m above ground at the selected locations of highest concentrations in the area under investigation.

The annual effective dose equivalent H (μSv/y) received by the population was calculated using the following formula [1]:

$$H = D\ (nGy/h) \times 0.7\ (Sv/Gy) \times 8760(h/y) \times 0.2$$

where D is the air absorbed dose rate.

The annual effective dose equivalent for population living in the Northern State as calculated for the 80 soil samples was found to be in the range 0.013 - 0.265 mSv, with a mean value of 0.10 ± 0.01 mSv.

The radiation hazards associated with the radionuclides were estimated by calculating the radium equivalent activity (Raeq). The radium equivalent activity was calculated using the following equation [8]:

$$Raeq = (A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077) \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The calculated values of Raeq for all 80 soil samples ranged from 22.8 to 444.5 Bq/kg, with a mean value of

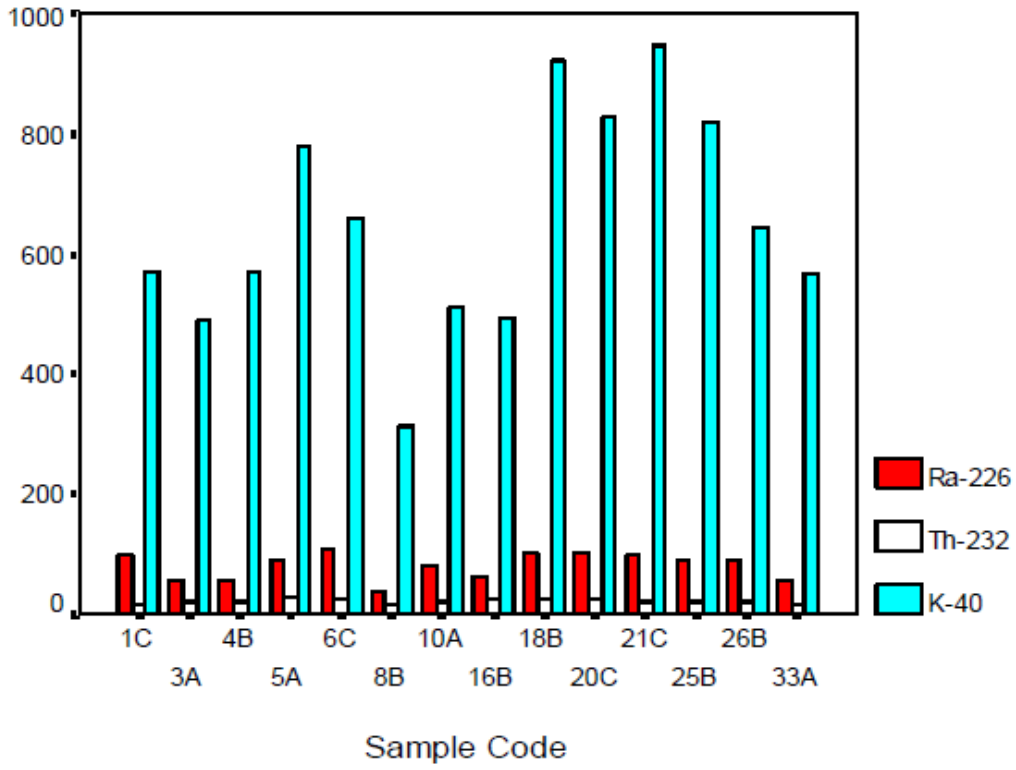

Figure 2 ^{226}Ra ,^{232}Th and ^{40}K activity concentrations for soil samples at selected locations

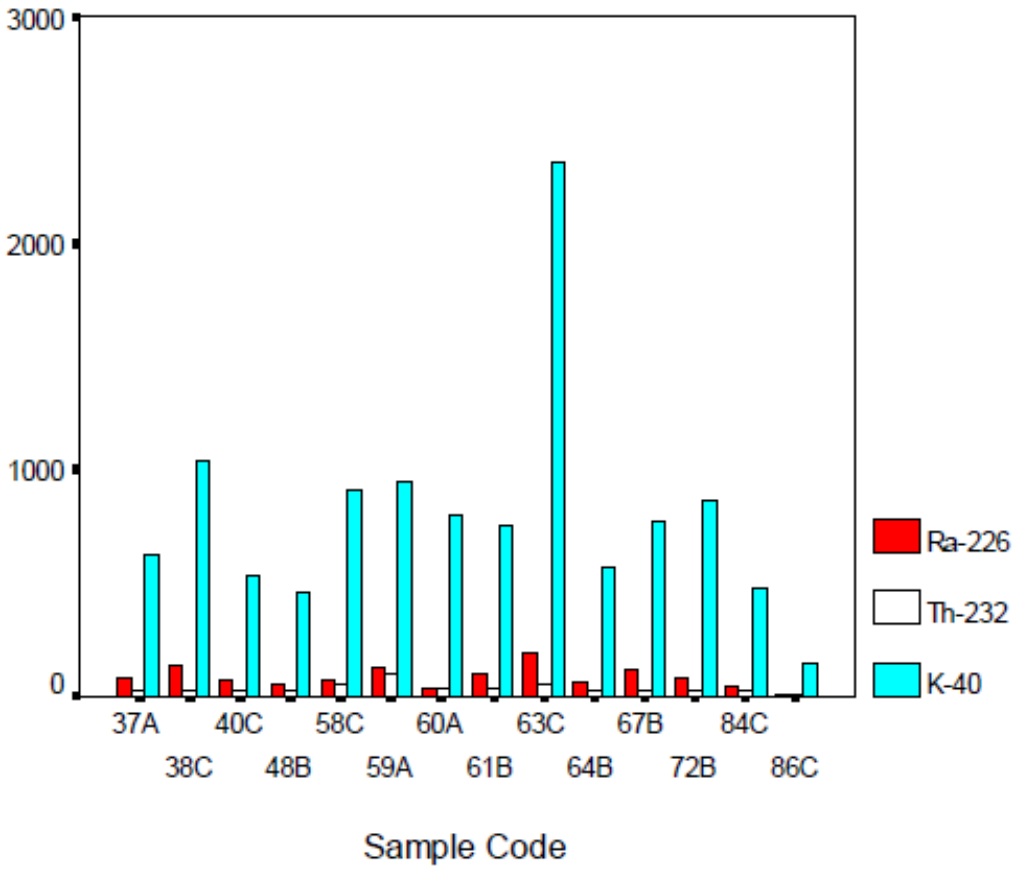

Figure 3 ^{226}Ra ,^{232}Th and ^{40}K activity concentrations for soil samples at selected locations

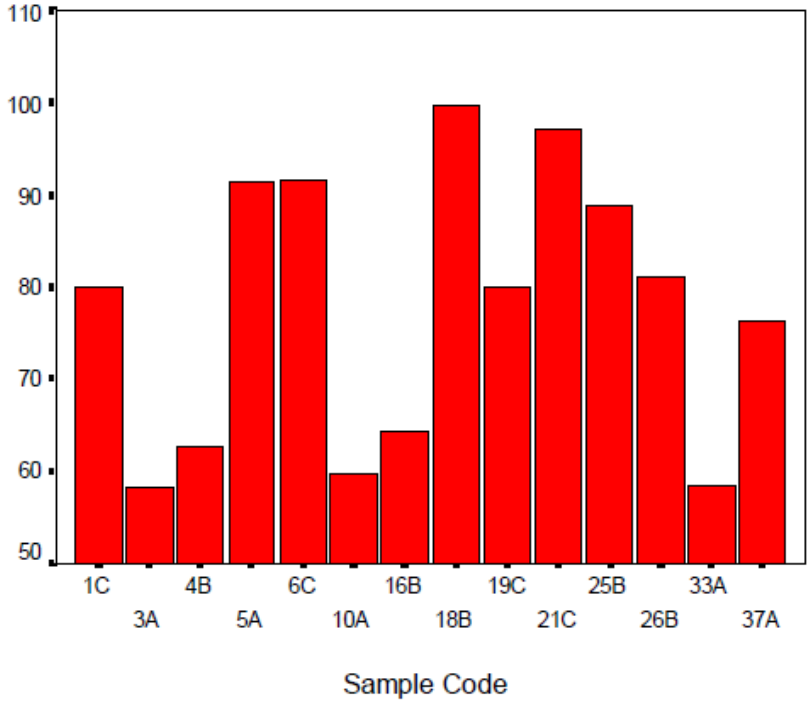

Figure 4 Outdoor absorbed dose rate in air due to gamma radiation for the measured soil samples at selected locations

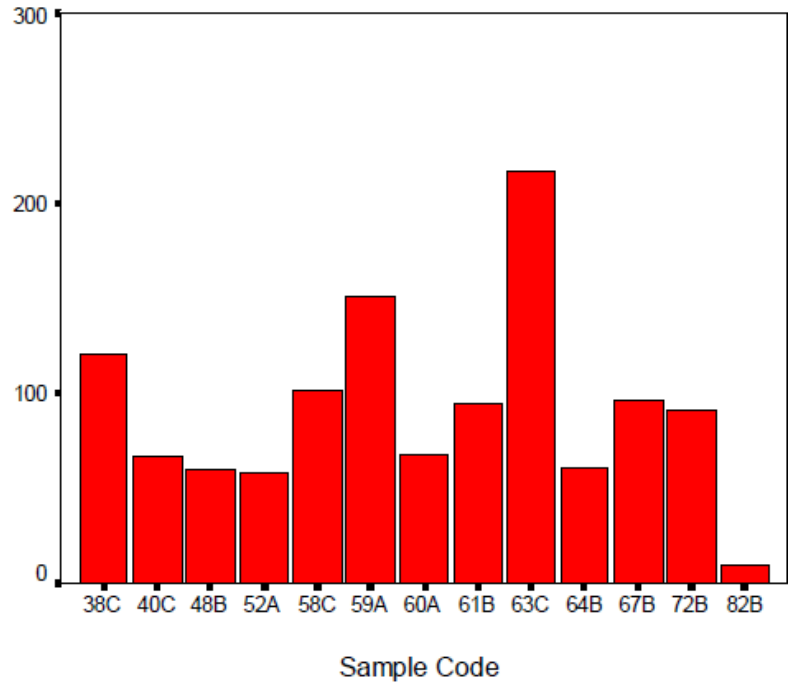

Figure 5 Outdoor absorbed dose rate in air due to gamma radiation for the measured soil samples at selected locations

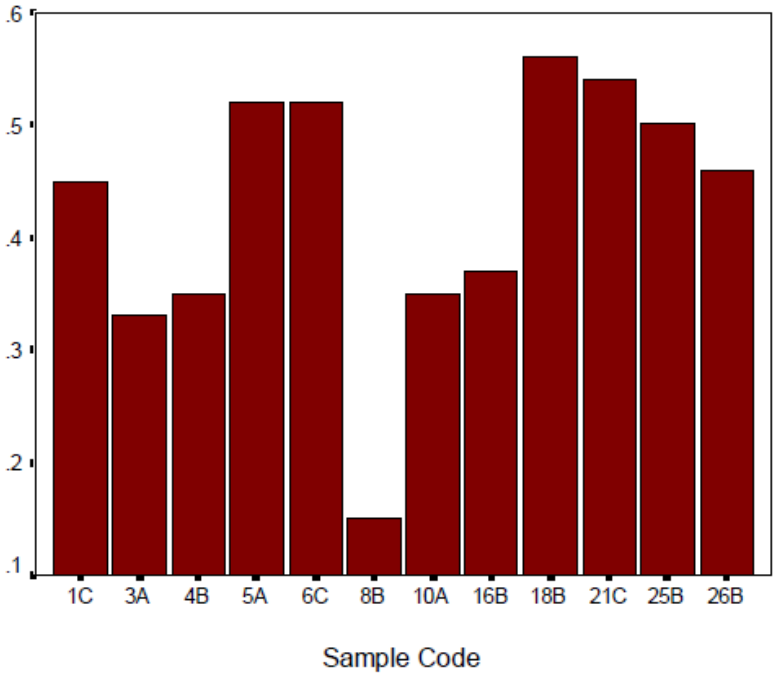

Figure 6 Values of external hazard index for the soil samples at selected locations

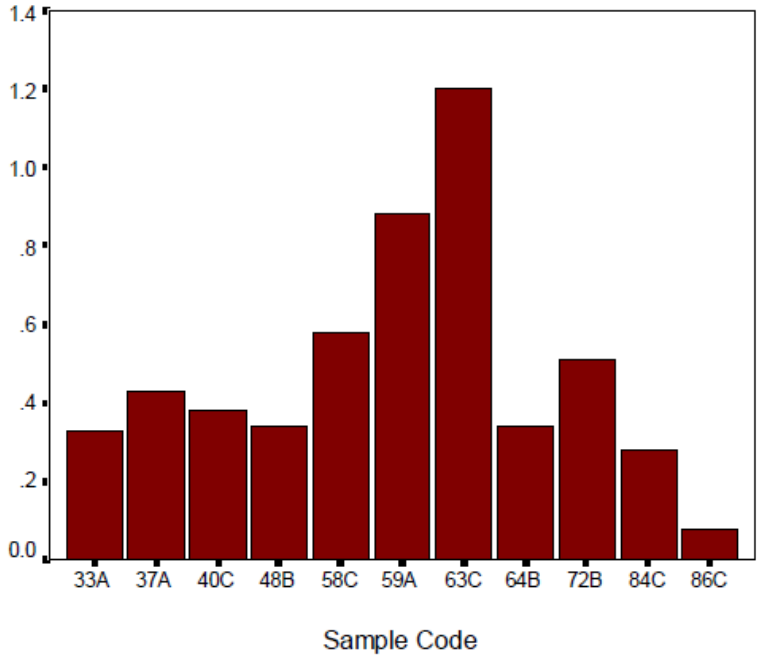

Figure 7 Values of external hazard index for the soil samples at selected locations

177.2 ± 14.7 Bq/kg, which is well below the recommended value of 370 Bq/kg(8).

External radiation hazard due to the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K is denoted by Hex. It is computed using the following expression (4):

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (4)$$

where A_{Ra} , A_{Th} and A_K represent activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. If the value of external radiation hazard index is found to be less than unity, then there is no outdoor radiation hazard(5).

The external radiation hazard index (Hex) varied from 0.06 to 1.2, with a mean value of 0.48 ± 0.04, which is less than the critical value of unity. This indicates that the soil samples were free from the potential danger of external radiation hazards. The measured values of external radiation hazard index for each of the selected locations of highest concentrations is shown in Figs. 6 and 7.It was also found that mean value of Hex for the soil samples analyzed in the present work was lower than the value reported earlier in Sudan of 0.6(8).

4. Conclusion

In the present investigation the natural radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for 80 surface soil samples collected from different locations in Northern State of Sudan were slightly higher than the worldwide average values.

The outdoor absorbed dose rates in air at 1m above ground were also slightly higher than the worldwide average values.

The radium equivalent activity mean value in the studied area was found to be lower

than the worldwide recommended value. The external radiation hazard index (Hex)

of the soil samples was found to be less than the recommended value of unity, indicating no outdoor radiation hazard.

Acknowledgements
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