ASSESSMENT OF NATURAL RADIOACTIVITY LEVELS IN THE SOIL OF DIRE DAWA CITY, ETHIOPIA

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Abstract. This study reports specific activity levels from the naturally occurring radionuclides ^{232}Th, ^{238}U and ^{40}K, in various geological formations of Dire Dawa city, Ethiopia. High resolution gamma ray spectrometry was used to assess the natural radioactivity levels concentration of ^{238}U, ^{232}Th and ^{40}K of soil samples. A total of 16 samples were collected from the city. The result revealed that the mean value of the specific activity ranged from 6.10±0.53 to 30.00±1.35 Bq·kg^{-1} for Uranium-238 (^{238}U), 12.56±0.73 to 102.46±4.63 Bq·kg^{-1} for Thorium-232 (^{232}Th) and 98.73±4.53 to 1182.83±49.11 Bq·kg^{-1} for Potassium-40 (^{40}K), with mean values of 19.97±2.42 Bq·kg^{-1}, 56.38±4.50 Bq·kg^{-1} and 716.59±68.43 Bq·kg^{-1}, respectively. The results of this study revealed an area of low gamma emitting radionuclides, which could not lead to significant health hazard to the exposed people. On average, there are no harmful radiations effects posed to the population who live in the study area; however, there are some spots in which the level of radioactivity is higher than the internationally allowable threshold.

Key words: Gamma spectroscopy, radioactivity, radionuclides, ^{232}Th, ^{238}U, ^{40}K.

INTRODUCTION

The natural radioactivity present in the environment is the main source of radiation exposure for humans and constitutes the background radiation level. Natural radionuclides in the soil generate a significant component of background radiation exposure to the population. The background radiation is mainly produced by about 60 abundantly distributed radionuclides [2].

The International Atomic Energy Agency (IAEA) suggests that approximately 82% of human beings are exposed to radiation doses beyond the recommended limit. The sources are cosmic, terrestrial and internal, as a result of inhalation or intake of radioactive substances. The latter is might be out of the control of people who are unaware of the corresponding risks. Recent studies [2, 5, 8, 14, 15, 23, 27] have reported different values regarding the effect of background radiation on human health. The gamma radiation generated by natural sources is mainly generated by

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primordial radionuclides that belong to the ^{232}Th and ^{238}U series and their radioactive decay products, as well as ^{40}K, which are present in the earth's crust at trace levels. Therefore, radionuclides with half-lives comparable with the age of the earth or their corresponding decay products existing in terrestrial material such as ^{232}Th, ^{238}U and ^{40}K are of great interest.

Radionuclides are encountered in terrestrial strata (soil or rocks) or aqueous media (ocean, sea, or lakes) and can be easily accumulated into the foot chain [25].

More specifically, natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the soils of each region in the world [28, 29]. As shown by different scholars [4, 10, 11, 20], the soil is a major source for natural radioactivity, and it is the source for the radiation-hazard for the population and a source for migration and transfer of radionuclides into the environment. Therefore, soil's natural-radioactivity is considered as a basic indicator for radiological contamination [26, 21].

This study focuses on assessments of radioactivity levels of soils selected from Dire Dawa city. The results can be used to determine the specific activity levels, to assess its impacts on the population and maintain reference data to ascertain changes in environmental radioactivity caused by industrial and other human activities.

MATERIALS AND METHODS

STUDY AREA AND SAMPLES COLLECTION

In this study, the measurement fields as a center of Dire Dawa city are selected. Dire Dawa is one of the city administrations in the eastern part of Ethiopia. The city is at an altitude of 1221 m, between 40°19' and 41°38' East longitude and 9°19' and 9°27' North latitudes. Locations of sampling points are determined with GPS (Global Positioning System) and locations are recorded.

The sampling points were randomly selected within the city. Figure 1 shows the map of the study area.

Sixteen soil samples ($S_1 - S_{16}$) were collected from the different sites of Dire Dawa city during October 16–18, 2018. The majority of the samples were taken from the residential regions following the main road. The sampling sites and their geographical positions are shown in Table 1.

Fig. 1. Topography map of Dire Dawa city showing the study locations (Maps, 2018) and stars shows the site where soils were collected.

Table 1

Coded samples based on the soil sampling

Sample code	Coordinates		Sample code	Coordinates	
	Latitude	Longitude		Latitude	Longitude
S_1	9° 36′03.2″N	41° 50′59.9″E	S_9	9° 35′25.9″N	41° 50′58.3″E
S_2	9° 35′53.3″N	41° 52′07.7″E	S_{10}	9° 36′24.4″N	41° 51′30.1"E
S_3	9° 35′49.9″ N	41° 52′27.6″E	S_{11}	9° 34′49.5″N	41° 51′26.2″E

S_4	9° $36'39.5''$N	41° $50'48.4''$E	S_{12}	9° $35'21.3''$N	41° $51'30.1''$E
S_5	9° $36'52.8''$N	41° $50'09.4''$E	S_{13}	9° $35'19.5''$N	41° $52'04.2''$E
S_6	9° $36'25.1''$N	41° $49'58.0''$E	S_{14}	9° $36'21.1''$N	41° $52'39.2''$E
S_7	9° $35'43.7''$N	41° $50'14.9''$E	S_{15}	9° $35'01.2''$N	41° $51'46.3''$E
S_8	9° $36'06.5''$N	41° 5040.40"E	S_{16}	9° $35'41.5''$N	41° $51'00.9''$E

The samples were collected in a polythene bag brought to the laboratory. The polythene bags were marked by the number S_1 to S_{16}. The samples were crushed and dried in oven at 110 ^oC for complete removal of moisture for 12 hours and finally crashed into fine powder by using a mortar. The powdered samples were packed in standard 400−700 g Marinelli beakers for gamma ray analysis.

Each sample was packed into 62.172 cm^3 standard size can and sealed tightly with an insulating tape around the opening of the containers for preventing the moisture contamination of samples. In order to maintain radioactive equilibrium between ^{226}Ra with its decay products in the uranium series and ^{228}Ra with its daughters in the thorium series, the packed Marinelli beaker was stored for a period of 4 weeks [1, 6, 12, 13].

The final sample preparation and all the gamma-ray spectrometry measurements [18] were performed in consultation with the experts of radiation detection laboratory of Ethiopian Radiation Protection Authority.

GAMMA RAY SPECTROMETRY

Gamma rays are emitted in radioactive decay along with alpha or beta radiations. Gamma rays have discrete energies given by Planck's equation:

$$E = nh\nu \quad (1)$$

where E is the energy of a beam of photons, h is Planck's constant, ν is the frequency of photons and n is the number of photons that compose the beam.

A gamma spectrometry system was used for measuring gamma rays emitted from soil samples. The employed gamma spectrometer was an n-type coaxial CAMBERRA high-purity germanium detector with a crystal diameter of 72.5 mm and a thickness of 72.5 mm (Prague, Czech Republic). Its detector has a relative efficiency of 70%, and energy resolution of 1.90 keV (FWHM) at 1333 keV and 1.05 KeV (FWHM) at 122 keV a peak-to-Compton ratio of 70:1. This spectrometer is surrounded by a copper shield of 6 mm in thickness and a lead shields of 4 cm in thickness to reduce the background of gamma radiation to minimum. For the measurement of low level radioactivity, a well shielded counting system is essential. The shielding reduces the radiations from background.

The background radiation level of the laboratory environment was later subtracted from the measured γ-ray spectra of each sample. At the end of the measurement, the region of interest, which was deducted from the background reading, was computed with a specialized template involving the energy, percentage error, count, uncertainty [21]. Specific activity, concentration and uncertainty in activity, gamma probability, and uncertainty in gamma probability, efficiency and uncertainty in efficiency were used to determine the radionuclide concentration in each sample.

ENERGY CALIBRATION

The purpose of the energy calibration is to match up the gamma ray energies detected with the correct channels in the computer program. This can be achieved by using a source with well-known peaks, observing and marking the peaks in the computer program and entering the energies that should be found in those channels, and allowing the computer program to extrapolate the correct energy for each channel from these results. The calibration of the spectrometer was performed using the Marinelli method [3]. Each sample and background data were counted for 86400 s. Gamma spectroscopy was used to determine the activities of ^{238}U, ^{232}Th, and ^{40}K.

SPECIFIC ACTIVITY

The specific activity in Becquerel per kilogram (Bq·kg^{-1}) for each radionuclide was calculated automatically by Genie-2000 software based on the following equation [19].

$$A = \frac{\frac{N_s}{t_s} - \frac{N_b}{t_b}}{\varepsilon(E_i) \cdot I_\gamma M_s} \quad (2)$$

where A is the specific activity of the radionuclide in the sample given in Bq·kg^{-1}, N_s net counts of the radionuclide in the samples, $N_{b,}$ net counts of radionuclide in the background, I_γ : gamma emission probability (gamma yield), $\varepsilon(E_i)$ peak efficiency of the detector at energy E_i, t_s sample counting time, t_b background measuring time and M_s mass of the sample (kg).

RESULTS AND DISCUSSION

The radioactivity of natural radionuclides, namely, uranium and thorium series, as well as ^{40}K, was investigated in soil samples. As it was noted by [29, 30], these radionuclides have a great contribution for background radiation which causes cancer for human beings.

As it was shown by [29] the world average specific activities are 35 Bq·kg^{-1}, 30 Bq·kg^{-1} and 400 Bq·kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively.

The results of the measurements of natural radionuclide (^{238}U, ^{232}Th and ^{40}K) specific activities in the 16 soil samples collected from the studied areas are summarized in Table 2.

Table 2

The specific activity of ^{238}U, ^{232}Th and ^{40}K in the soil samples

Sample code	Specific activity (Bq·kg^{-1})			Sample code	Specific activity (Bq·kg^{-1})		
	^{238}U	^{232}Th	^{40}K		^{238}U	^{232}Th	^{40}K
S_1	21.30±6.40	96.11±4.37	824.23±34.37	S_9	16.78±0.77	72.47±3.29	410.81±17.14
S_2	29.09±1.32	61.89±2.93	792.22±33.17	S_{10}	22.90±1.04	67.87±3.11	1158.09±48.04
S_3	17.88±0.80	39.49±1.87	566.24±23.66	S_{11}	23.07±1.05	29.93±2.78	1182.83±49.11
S_4	6.10±0.53	12.56±0.73	98.73±4.53	S_{12}	26.13±5.71	53.61±2.55	1182.50±49.20
S_5	21.84±1.01	88.17±3.99	717.78±29.89	S_{13}	10.39±0.56	33.63±1.65	887.77±36.99
S_6	30.00±1.35	102.46±4.63	662.46±27.63	S_{14}	28.37±1.26	95.48±4.38	664.32±27.70
S_7	15.52±0.76	26.41±1.33	295.52±12.55	S_{15}	14.85±0.70	74.80±3.39	815.65±33.86
S_8	20.59±0.95	44.67±2.10	563.35±23.53	S_{16}	14.63±14.50	28.85±28.85	642.91±643.46

Table 3

The average, maximum, minimum and worldwide average activity concentration of radio nuclides

	Specific activity (Bq·kg^{-1})		
	^{238}U	^{232}Th	^{40}K
Average	19.97±2.42	56.38±4.50	716.59±68.43
Min	6.10±0.53	12.56±0.73	98.73±4.53
Max	30.00±1.35	102.46±4.63	1182.83±49.11
Worldwide average	35	30	400

The minimum specific activity of ^{238}U was observed in sample S_4, which was (6.10 ± 0.53 Bq·kg^{-1}) and a maximum specific activity for the sample S_6 (30.00 ± 1.35 Bq·kg^{-1}), with an average of 19.97 ± 2.42 Bq·kg^{-1} shown in Table 3. The maximum specific activity was found in site S_6 this due to the location of the site and the types of soil collected there. The site S_6 was found around one of the main rivers crossing the city. Moreover, the specific activity of ^{238}U was close to the world average value of 30 Bq·kg^{-1}, whereas for the other soil samples the specific activities of the studied radionuclides were below average [29].

For ^{232}Th, the minimum was 12.56 ± 0.73 Bq·kg^{-1} (in sample S_4) and the maximum was 102.46 ± 4.63 Bq·kg^{-1} (in sample S_6) with an average of 56.38 ± 4.53 Bq·kg^{-1}. As it was noted in the above discussion, for ^{232}Th the minimum specific activity was found in the same site as for ^{238}U.

For ^{40}K the minimum was 98.73 ± 4.53 Bq·kg^{-1} (sample S_4) and the maximum was 1182.83 ± 49.11 Bq·kg^{-1} (sample S_{11}) with an average value of 716.59 ± 68.43 Bq·kg^{-1}. The average specific activity of ^{40}K was less than the world average [29]. On the other hand, the specific activity levels of ^{40}K in the remaining sites were higher than average (Table 4). The reason could be attributed to differences in their geological nature.

The other main concern of this study was the comparison of specific activity levels of the soil of the city with some other countries, as shown in Table 4. The average specific activity of the radionuclide ^{238}U is 19.97±2.42 Bq·kg^{-1}, higher than the value found in Nigeria by [22] and less than in Turkey [23]. For ^{232}Th, the average specific activity was obtained in the study area 56.38±4.50 Bq·kg^{-1} which was higher than in Malaysia [29].

Table 4

Comparison of ^{238}U, ^{232}Th, and ^{40}K average concentrations of soil samples with the available data from different countries

	Specific activity (Bq·kg□1)	References

Country	^{238}U	^{232}Th	^{40}K	
Egypt	17	18	320	[29]
USA	40	35	370	[16]
China	32	41	440	[31]
Malaysia	67	82	310	[29]
Iran	28	22	640	[29]
Denmark	17	19	460	[17]
Poland	26	21	410	[9]
Spain	33	33	470	[29]
Nigeria	18	22	210	[22]
Turkey	48.4	20.5	744.8	[23]
Pakistan	45	59	648	[7]
Ethiopia, Dire Dawa	19.97	56.38	716.59	Present study
Worldwide average	35	30	400	[29]

CONCLUSIONS

The study is an evaluation of the radio activity level of the radionuclides uranium-238, thorium-232, and Potassium-40, for 16 selected sites in Dire Dawa city. In this study we have determined the specific activities of these radionuclides using gamma ray spectrometry. The specific activity values of ^{40}K in most of the sites were higher than the worldwide mean values but for ^{238}U and ^{232}Th they were less than average in most of the selected sites. The data reported in this study can be used as baseline values for producing a radiological map of the studied area.

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