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The activity concentrations of radionuclides ^{226}Ra, ^{232}Th and ^{40}K of soil samples in the case of Metekel Zone, Ethiopia

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Abstract. In this paper, we have studied the concentration levels and corresponding radiological hazard indices of natural radioactive elements such as radium-226, thorium-232, and potassium-40 in soil samples collected from Metekel Zone, Ethiopia. We have determined the concentration levels with the help of gamma ray spectrometry. Accordingly, we obtained the average values for radioactive concentrations of radium, thorium, and potassium to be 64 Bq/kg, 70 Bq/kg, and 330 Bq/kg, respectively. The radiological hazard has been also determined from the pertinent concentration levels of radium, thorium and potassium isotopes. Therefore, we obtained that the radioisotopes have heterogeneous distribution which must be caused by the nature and types of the soil in the area where this investigation was conducted for.

1 Introduction

Man is continuously exposed to natural radiations that are present on earth since its creation. The knowledge of radionuclides distribution and radiation levels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and extraterrestrial sources [1]. Terrestrial radiation is due to the radioactive nuclides present in the varying amounts in soils, building materials, water, rocks and atmosphere while the extraterrestrial radiation originates from the outer space as primary cosmic rays [2]. Natural radiations arises mainly from primordial nuclides such as ^{40}K and the radionuclides from ^{226}Ra and ^{232}Th series and their decay products which occur at trace levels in all ground formations [1,3]. Soil, being the major source of natural radioactivity, is the raw material for buildings used in Metekel Zone.

Natural radioactivity present in soil produces gamma radiations in the environment and changes the background radiations level. Everyone in the planet is exposed to these background levels of ionizing radiations. External exposure occurs as a result of irradiation and internal exposure because of inhalation and ingestion [3]. Since the natural radiation is the largest contributor to the external dose of world population, the assessment of gamma radiation dose from natural sources is of particular importance [4–6].

Thus, Radon is decay product of radium (^{226}Ra) that is the part of uranium (^{238}U) decay chains. Radon and its progenies are the major contributor in the atmosphere which is responsible for about half of radiation dose received by general population [1,2]. Radon is also the second major cause of lung cancer after smoking [5,6]. Indoor radon concentration depends upon the existence of natural radioactivity in the underlying soil or rock of a dwelling [5–7]. So, it is important to assess the radiation hazards arising due to use of soil samples in construction of dwellings [8]. Many researchers have estimated the natural radioactivity levels and associated health hazards in the world [8–13].

In this study, the natural radioactivity levels in the soil samples of Metekel Zone are measured by gamma ray spectrometery using p−type high purity germanium semiconductor detector. The work in the study area has been carried out for the first time and will be of general interest to the inhabitants as the knowledge of radioactivity levels in the soil samples will provide awareness among them about the safety guiedrule development and radiological effects on their health. The results of this study have also been compare with the corresponding results found across the world.

2 Methodology

2.1 Location of study area

Benishangul Gumuz is one of the regions of Ethiopia in North west part of it. Metekel zone is therefore found in this region and covers two–third of the total area of the

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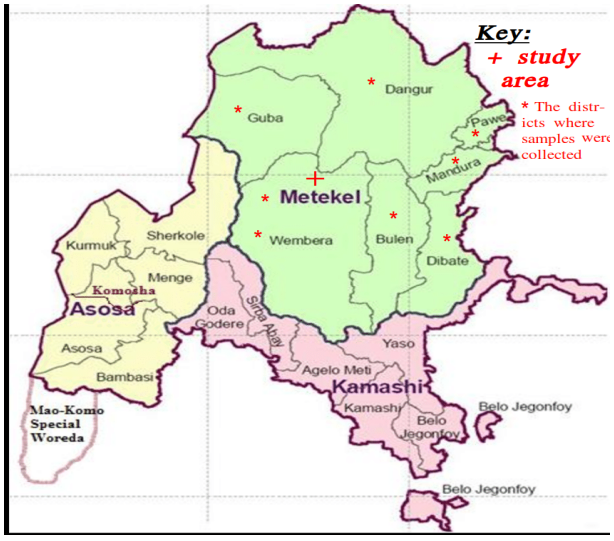

Fig. 1. Map of the study sites in Benishangul Gumuz province, Ethiopia. The astriks shown the areas (districts) where the samples were collected [15].

region [14]. It is bordered on the south and southwest by Kamashi, on the west by Sudan, and on the north and east by the Amhara Region. The Abay River defines the Zone's boundaries with Kamashi, while the Dinder River defines part of its boundary with the Amhara Region as shown in Figure 1 [15]. The administrative center of Metekel Zone is Gilgil Beles. The highest point is Mount Belaya which has 3,131 meters and is part of the Dangur range [15].

2.2 Sampling techniques

The study sites are highly mineral rich (specially gold rich) areas and the income of the population around these places is traditional gold mining in addition to bamboo and crop production. Also, Metekel Zone is the location of seven districts (woredas): Guba, Dangur, Pawe, Mandura, Wenbera, Bulen, and Dibate. All the soil types such as Sandy loam, Sands, Silt, Clay, Silty clay, Clay loam, and so on are found in these districts [14]. For this study, six different types of soil samples: Sandy loam, Sands, Silt, Clay, Silty clay and Clay loam were collected from each distric. Specifically, We have taken 24 samples from Dangur and Wombera, 4 samples from each soil types, and 18 samples from Bullen and Guba woredas in which 3 samples from six soil types. However, a total of 12 samples were taken from each of Pawe, Mandura and Dibate districts and 2 from each soil types based on the area of districts as shown in Figure 1. During sample collection, we have taken the samples from the surface of the earth at some depth and from predpared soils for constructions equivalently. The total of 120 representative samples, from North West Ethiopia were collected using a grab sampling method. When we have sampled selected soil samples, the depth of holes below the surface of earth were 0.5 m, which helps to obtain a better mineral content that could give the expected results. In addition, we used a distance of 2–3 m between samples based on the area of study sites, which allowed us to take proposed samples. These samples were collected in a new and transparent plastic bag containers from the soil surface of depth 0.5 m and cataloged according to location and type where they collected. A total of one hundred twenty samples were collected in seven Districts of Metekel Zone based on the geographical location.

2.3 Gamma spectrometric analysis of samples for the radionuclides activities

Each sample was grained and dried in a temperature controlled oven at the temperature of 115 °C for about 15 hours to remove moisture, and also sieved through 200 μm mesh to obtain the fine powder of a homogeneous sample. About 100 g of samples were packed in gas tight, radon impermeable, cylindrical plastic containers (Marinelli beakers) which has 7 cm diameter and 10 cm height for gamma activity analysis [6]. Before measurements, radon sealing is done by placing the sample container into an aluminum-lined bag and evacuating it using a Henkovac Mini Eco commercial vacuum packaging machine. The containers were kept packed for thirty two days in order to ensure that the short lived progeny of ^{226}Ra and ^{222}Rn have arrived equilibrium with their respective parent radionuclides.

Gamma ray spectrometery measurements were conducted with 45% efficiency p−type high purity germanium detector coupled to a multichannel analyzer was used for radioactivity measurements [4–6]. The selected detector has a high efficiency for typical samples, the high purity germanium detector is the Canberra Broad Energy Germanium (CBEGe) which exhibits lower background than typical coaxial detectors since it is more transparent to high energy gamma from naturally occurring radionuclides such as ^{40}K and the Thorium series of ^{208}Tl [6]. The detector was shielded in a 5 cm thick lead on all sides including top to reduce background due to cosmic ray component by almost 98% and the inner sides of the lead lined with 2 mm copper foils. The spectrum acquisition and processing were made possible by coupling the detector output to an ORTEC Multi-Channel Analyzer (MCA) alongside a PC equipped with Genie 2000 evaluation software that matches gamma energies to a library of possible isotopes. Prior to counting the samples, efficiency and energy calibrations of the detector were carried out for various energies of interest in the selected sample geometry following the calibration procedures described by the International Atomic Energy Agency [16]. The efficiency calibration was achieved by using a 450 g mixed Canberra soil standard containing ^{125}Sb, ^{155}Eu, ^{54}Mn, ^{65}Zn, and ^{40}K in Marinelli beaker in the energy range of 35.5 keV to 1460.8 keV. The standard soil sample container and those of the experimental samples were geometrically identical. Point sources of ^{241}Am (59.54 keV), ^{137}Cs (661.66 keV) and ^{60}Co (1173.24 and 1332.49 keV) from IAEA were used for the energy calibration. The background count was determined by counting an empty beaker container having the same dimensions with those carrying the samples. The background spectrum was subtracted from the

measured sample spectra to obtain the net radionuclide activities. The counting time of each sample and background was obtained at 40,000 seconds since the spectrum was clearly distinct at this time with good statistics. Considering the low-intensity photons emission and slow decay rates, the activities of ^{226}Ra and ^{232}Th are hard to detect directly from the detector, therefore, under radioactive secular equilibrium condition, the photo peaks of their short-lived decay products were used to assess and evaluate the activity concentration of ^{226}Ra and ^{232}Th [17–22]. Weighted average activity was considered for a nuclide having more than one peak in the spectrum. The gamma-ray photopeak of ^{228}Ac (911.1 keV) and ^{208}Tl (583.1 keV) were used to determine the activity of ^{232}Th while ^{214}Bi (1120.3 and 609.3 keV) and ^{214}Pb (351.9 keV) were used for the activity of ^{226}Ra [22,23]. The activity of ^{40}K was determined from its single gamma line of 1460.8 keV [24]. The specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in each samples, in Bq kg^{-1}, were then computed using equation [22–24]

$$A = \frac{W}{\epsilon PMt} \tag{1}$$

where W is the net counts of gamma-ray, ϵ is the photo peak efficiency of a detector, P is the absolute transition of gamma decay, t is counting time in seconds and M mass of the final prepared and dried sample in kilogram which is stored in the cylindrical plastic container for the purpose of experiment.

3 Results and discussion

The specific activities of the natural radionuclides of the ^{226}Ra, ^{232}Th and ^{40}K were evaluated by using gamma−ray spectrometry in 120 different soil samples collected from the districts in the Metekel Zone. All results including the minimum, maximum and mean values, of the above natural radioisotopes are depicted for the different districts in Table 1. The results taken from the samples prepared for constructions and taken from the ground including the same soil types were almost uniformly distributed in all districts.

The activity levels ($\pm$SD) for ^{226}Ra, ^{232}Th and ^{40}K in all soil samples ranged from 10 ± 1 to 146 ± 2 Bq kg^{-1} with a mean of 64 ± 16 Bq kg^{-1}, 26 ± 4 to 167 ± 4 Bq kg^{-1} with a mean of 70 ± 19 Bq kg^{-1} and 94 ± 13 to 540 ± 28 Bq kg^{-1} with a mean of 330 ± 120 Bq kg^{-1}, respectively. The world′s mean values of ^{226}Ra, ^{232}Th and ^{40}K are 35, 30 and 400 Bq kg^{-1}, respectively [7]. The mean of ^{40}K observed in this study was significantly lower than the world′s mean values, whereas the mean concentrations of ^{226}Ra and ^{232}Th were higher than the world′s mean values of 35 and 30 Bq kg^{-1}, respectively.

As can be seen from Table 1, the highest mean activity of ^{226}Ra was determined in the Bulen district and the Mandura district showed the lowest mean levels of ^{226}Ra, the Guba and Wenbera districts showed the lowest value $\left(43 \pm 16\ Bq\ kg^{-1}\right)$ and the highest $\left(84 \pm 25\ Bq\ kg^{-1}\right)$ activity concentrations of ^{232}Th, respectively. The activity concentrations of radioisotope ^{40}K were found to be minimum in the Dibate $\left(209 \pm 60\ Bq\ kg^{-1}\right)$ and maximum in the Bulen $\left(468 \pm 70\ Bq\ kg^{-1}\right)$ areas.

Almost all the mean activity concentrations of ^{226}Ra and ^{232}Th in soil types of samples were higher than the world average value, on average, the activities of ^{40}K were lower than the worldwide proposed values. Sandy loam samples showed the lowest ^{226}Ra and ^{232}Th activity concentration values and Clay samples have had the lowest ^{40}K activity concentration values and all these values were lower than reported international's mean values [7].

Sampled studied levels tabulated for reported data of other countries for comparison are given in Table 2. For example, the ^{226}Ra the measured mean values for soil samples was higher than the concentration for Dhanbad city (Jharkhand), Turkey, Rize Province−Turkey, Istanbul, Kuwait, Northern Jordan, Eastern Yunnan China, Iran, Thai Lemongras, Saudi Arabia, Iraqi Kurdistan Region, Northern Regions of Oman and Niabi Faisalabad (Pakistan), and it was lower than the activity concentration of Sahiwal−Pakistan, North Cyprus, Malaysia, Southern Kenya, India, Penang−Pakistan and Kaduna State Nigeria. For the case of ^{232}Th concentrations, the obtained value was higher than for Dhanbad city (Jharkhand), Turkey, Sahiwal−Pakistan, Turkey, Istanbul, Kuwait, Northern Jordan, Eastern Yunnan China, Iran, Thai Lemongras, Saudi Arabia, Iraqi Kurdistan Region, Northern Regions of Oman and Niabi Faisalabad (Pakistan), whereas it was lower than Malaysia, Kaduna State Nigeria, Southern Kenya and India. The obtained mean concentration value of ^{40}K was 330 Bq kg^{-1}. This was exactly higher than for Turkey, Northern Jordan, Eastern Yunnan China, Kaduna State Nigeria and Northern Regions of Oman.

According to our results, the spread out of ^{226}Ra, ^{232}Th and ^{40}K in soils was not the same. The situation which makes different distribution across the study places with respect to exposure to radiation was defined in terms of radium equivalent activity (Ra$_{eq}$) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K [6]. The radium equivalent activity was estimated through the following relation [25]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{2}$$

where A_{Ra}, A_{Th} and A_K are concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The computed mean Ra$_{eq}$ values are presented in Table 3 for the different soil types and the different districts where they are collected. The minimum $\left(133\ Bq\ kg^{-1}\right)$ and the maximum $\left(229\ Bq\ kg^{-1}\right)$ values of Ra$_{eq}$ were found in Silt and Silty clay soil types in the Guba, Wenbera and Bulen districts, respectively. While the mean Ra$_{eq}$ values of all the measured soil samples were lower than the limit value of 370 Bq kg^{-1} requested by Organization for Economic Cooperation and Development (OECD) [26].

The number of indices dealing with the assessment of the excess gamma radiation emitting from construction materials such as outdoor and indoor hazard indices and

Table 1. The measured concentrations $\left(\mathrm{Bq\ kg^{-1}}\right)$ of ^{226}Ra, ^{232}Th and ^{40}K in selected soil samples according to different districts in Metekel and types.

	^{226}Ra			^{232}Th			^{40}K		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Districts									
Guba	15 ± 1	90 ± 10	60 ± 15	22 ± 4	59 ± 15	43 ± 16	230 ± 5	450 ± 20	290 ± 100
Dangur	23 ± 2	110 ± 12	70 ± 18	30 ± 4	70 ± 9	52 ± 11	170 ± 7	600 ± 28	324 ± 150
Pawe	32 ± 2	105 ± 9	69 ± 23	33 ± 5	120 ± 4	64 ± 19	109 ± 4	509 ± 27	340 ± 150
Mandura	17 ± 1	87 ± 3	40 ± 21	27 ± 1	106 ± 5	77 ± 11	178 ± 2	480 ± 35	274 ± 120
Wenbera	16 ± 2	89 ± 4	42 ± 18	33 ± 1	148 ± 12	84 ± 25	249 ± 7	478 ± 13	365 ± 70
Bulen	30 ± 1	140 ± 2	73 ± 11	52 ± 4	94 ± 3	79 ± 23	274 ± 3	698 ± 23	468 ± 170
Dibate	19 ± 1	103 ± 3	55 ± 15	41 ± 8	86 ± 1	69 ± 18	154 ± 6	396 ± 2	209 ± 60
Types									
Sandy loam	10 ± 1	77 ± 2	49 ± 20	26 ± 4	60 ± 1	42 ± 16	120 ± 5	540 ± 28	309 ± 120
Sands	30 ± 2	100 ± 10	76 ± 21	42 ± 4	87 ± 5	62 ± 10	115 ± 8	529 ± 25	298 ± 120
Silt	42 ± 2	118 ± 9	78 ± 21	40 ± 5	167 ± 4	90 ± 19	129 ± 4	429 ± 27	290 ± 110
Clay	27 ± 1	107 ± 3	67 ± 21	47 ± 1	136 ± 5	87 ± 11	188 ± 2	389 ± 35	244 ± 50
Silty clay	36 ± 2	139 ± 4	93 ± 18	59 ± 1	118 ± 12	81 ± 25	160 ± 7	378 ± 13	265 ± 70
Clay loam	40 ± 1	146 ± 2	82 ± 16	48 ± 4	104 ± 3	76 ± 28	94 ± 3	391 ± 12	320 ± 120

Table 2. Comparison of mean activity concentrations $\left(\mathrm{Bq\,kg^{-1}}\right)$ with studied results in soil samples from some selected countries.

Countries	^{226}Ra	^{232}Th	^{40}K	References	Countries	^{226}Ra	^{232}Th	^{40}K	References
Dhanbad city (Jharkhand)	44	62	570	[5]	Al-Qadisiyah Governorate	NA	5	450	[43]
Turkey	50	40	324	[6]	Southestern Kenya	195	409	915	[44]
Sahiwal, Pakistan	86	62	427	[33]	India	70	77	1028	[45]
Rize Province−Turkey	25	52	345	[34]	Iran	24	26	458	[46]
Istanbul	28	33	388	[35]	Thai Lemongrass	26	55	477	[47]
North Cyprus	84	54	594	[36]	Saudi Arabia	23	24	790	[48]
Kuwait	18	15	385	[37]	Iraqi Kurdistan Region	11−16	9−11	242−850	[49]
Northern Jordan	43	27	291	[38]	Penang, Malaysia	80	56	516	[50]
Malaysia	396	165	835	[39]	Northern regions of Oman	10−43	2.4−21	42−224	[51]
Eastern Yunnan, China	28	24	97	[40]	Niabi, Faisalabad, Pakistan	29−33	52−60	614−671	[52]
Coal-fired power plant, China	27	53	765	[41]					
Kaduna State, Nigeria	128	86	237	[42]	**Western, Ethiopia**	**64**	**70**	**330**	**This study**

gamma concentration indices has been given by several researchers [1,2,27–29]. In this study, the gamma index (I_γ) was computed as recommended by the European Commission (EC) and used by [5,30]:

$$I_\gamma = \frac{A_{Ra}}{300\ Bq\ kg^{-1}} + \frac{A_{Th}}{200\ Bq\ kg^{-1}} + \frac{A_K}{3000\ Bq\ kg^{-1}} \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The values of I_γ calculated from the studied values of ^{226}Ra, ^{232}Th and ^{40}K are shown in Table 3 for different soil types and the districts where they were collected. The average values of I_γ for the studied samples varied in the range between 0.48 and 0.81 for types of soil and 0.52 and 0.79 for the districts which were less than the critical value of 1.

At this particular time, many alpha indices have been presented to assess the exposure level due to radon inhalation originating from construction materials [30]. The alpha index was calculated by using formula:

$$I_\alpha = \frac{A_{Ra}}{200\ Bq\ kg^{-1}} \quad (4)$$

where A_{Ra} is the concentration of ^{226}Ra in the unit of Bq kg^{-1} that assumed in equilibrium with ^{238}U. The recommended lower and upper level of ^{226}Ra activity concentrations in soil are 100 and 200 Bq kg^{-1}, respectively, as requested by International Commitee on Radiation Protection (ICRP) [31]. This implies that, when the materials are used for construction, the recommended level of lower and upper limits concentration of ^{226}Ra 100 Bq kg^{-1} and 200 Bq kg^{-1}, for which $I_\alpha = 1$. The mean calculated I_α values for the studied soil samples are given in Table 3 for the different soil types and the districts where they were collected. The values of I_α ranged from 0.25 to 0.47, with the mean value of 0.37. For the safely use of soil in the building of dwellings and for production of crops, I_α should be less than unity. Accordingly, our result shows the mean values calculated for I_α indices were less than unity for all study sites.

There is concern that some of the buildings will cause too much radiation doses to the human body due to gamma rays emitted by ^{214}Pb and ^{214}Bi progeny of ^{226}Ra and ^{232}Th decay chains, respectively and the contribution of ^{40}K to the total body radiation dose is not ignored.

Table 3. The calculated results for radiological health indices parameters in the different districts in Metekel and the soil types.

	Ra_{eq} $(Bq\ kg^{-1})$	I_γ	I_α	D $(nGyh^{-1})$	AED $(mSvy^{-1})$	Ra/Th	Th/Ra
Districts							
Guba	143 ± 54	0.52 ± 0.46	0.30 ± 0.05	126 ± 39	0.62 ± 0.20	1.40 ± 0.24	0.72 ± 0.10
Dangur	169 ± 46	0.60 ± 0.17	0.35 ± 0.09	148 ± 41	0.73 ± 0.20	1.35 ± 0.34	0.74 ± 0.11
Pawe	187 ± 62	0.60 ± 0.22	0.35 ± 0.12	161 ± 54	0.79 ± 0.27	1.08 ± 0.20	0.93 ± 0.13
Mandura	171 ± 46	0.61 ± 0.17	0.20 ± 0.11	143 ± 41	0.70 ± 0.20	0.52 ± 0.12	1.93 ± 0.33
Wenbera	190 ± 62	0.68 ± 0.21	0.21 ± 0.09	160 ± 50	0.79 ± 0.25	0.50 ± 0.20	2 ± 0.30
Bulen	222 ± 57	0.79 ± 0.21	0.37 ± 0.06	192 ± 49	0.94 ± 0.24	0.92 ± 0.08	1.08 ± 0.10
Dibate	170 ± 45	0.60 ± 0.16	0.28 ± 0.07	143 ± 38	0.70 ± 0.19	0.80 ± 0.03	1.26 ± 0.20
Types							
Sandy loam	133 ± 52	0.48 ± 0.19	0.25 ± 0.10	116 ± 46	0.60 ± 0.23	1.17 ± 0.25	0.86 ± 0.08
Sands	188 ± 45	0.66 ± 0.16	0.38 ± 0.11	162 ± 40	0.80 ± 0.20	1.23 ± 0.10	0.20 ± 0.08
Silt	229 ± 57	0.81 ± 0.20	0.39 ± 0.11	194 ± 49	0.95 ± 0.24	0.87 ± 0.22	1.30 ± 0.11
Clay	210 ± 41	0.74 ± 0.14	0.34 ± 0.11	177 ± 35	0.87 ± 0.17	0.77 ± 0.05	1.30 ± 0.05
Silty clay	229 ± 59	0.80 ± 0.21	0.47 ± 0.09	196 ± 50	0.96 ± 0.25	1.15 ± 0.22	0.87 ± 0.06
Clay loam	215 ± 65	0.76 ± 0.23	0.41 ± 0.08	185 ± 55	0.91 ± 0.48	1.08 ± 0.04	0.93 ± 0.28

The absorbed dose rate in indoor air due to gamma ray release from concentrations of ^{226}Ra and ^{232}Th and ^{40}K was estimated using the formula recommended by EC [30] and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [32]. In the UNSCEAR and the European Commissions reports, the dose conversion coefficients were calculated for the standard room center. Dimensions of the room were $4\,\mathrm{m} \times 5\,\mathrm{m} \times 2.8\,\mathrm{m}$. Thicknesses of walls, floor and ceiling and density of the structures were 20 cm and $2350\,\mathrm{kg\,m^{-3}}$ (soil), respectively.

$$D = \alpha A_{Ra} + \beta A_{Th} + \gamma A_K \tag{5}$$

where D is indoor absorbed dose rate and α, β and γ are the dose rates per unit activity concentrations of Ra, Th and K $(nGyh^{-1}/Bq\ kg^{-1})$, respectively. The values of α, β and γ were taken to be 0.92, 1.1 and 0.08, respectively [30]. By identifying the soil types and number of districts, we have collected the samples and measured the required terms. As a country, we do not have safety rules or guidelines for radiation protection and housing standards. Therefore, we used the EC room standard for this investigation.

The absorbed dose rates in indoor air calculated from the measured activities in different soil samples are also provided in Table 3 (column 5) for the different soil types and the study areas where they were collected. The measure intake dose rate in indoor air was found to vary from 116 to 196 $\mathrm{nGyh^{-1}}$ with a mean of 172 $\mathrm{nGyh^{-1}}$. It was higher than the world mean populated weight value of 84 $\mathrm{nGyh^{-1}}$. Results depicted in Table 3 tells that the lower and the higher received dose rates in air are produced by Sandy loam and Silty clay, respectively.

It is not common to use to use natural ventilation of the houses, as the local community uses the old method of house building. The houses they build are very narrow, have no windows, and no fresh air moving easily. As a result, they are more susceptible to various health problems. To estimate the periodical effective dose in indoor, it must be to consider that: (a) the conversion coefficient $(0.7\ Sv\ Gy^{-1})$ from absorbed dose in air to effective dose and (b) the indoor habitable factor (∼80% for population). Therefore, the successful dose rate in mSv y^{-1} unit was estimated by using the relation

$$AED = D \times 8760\mathrm{hy^{-1}} \times 0.7 \times 0.8 \times 10^{-6}. \tag{6}$$

The calculated values for the annual effective dose (AED) ranged from 0.60 to 0.96 mSv, with a mean value of 0.85 mSv. The corresponding annual effective dose rate from Sandy loam, Sands, Silt, Clay, Silty clays and Clay loam was slightly below the dose criterion of 1 mSv y^{-1}. In general, the average result of AED is approximate to 1 $\mathrm{mSvy^{-1}}$.

4 Conclusions

The activities of the naturally ability radionuclides of the ^{226}Ra, ^{232}Th and ^{40}K in the soil samples collected from agricultural and collected for building in North West Ethiopia were measured by using the technique of gamma ray spectrometry with HPGe detector. The calculated results may be useful in the assessment of the exposures and the radiation doses due to the naturally occurring radioactive material contents in soil samples. The overall average concentrations of ^{226}Ra, ^{232}Th and ^{40}K were 64, 70 and 330 Bq $\mathrm{kg^{-1}}$, respectively. The obtained mean concentrations of ^{226}Ra and ^{232}Th in the studied soil samples are above the world's quoted values of 35 and 30 Bq $\mathrm{kg^{-1}}$, respectively, however, the mean concentration of ^{40}K in the samples is lower than the corresponding typical value of 400 Bq $\mathrm{kg^{-1}}$ [6].

The results presented in this work show that the mean values of Ra_{eq}, I_γ, I_α, the indoor absorbed dose rate and the annual effective dose rate in soil samples are 201 Bq $\mathrm{kg^{-1}}$, 0.71, 0.37, 172 $\mathrm{nGyh^{-1}}$ and 0.85 $\mathrm{mSvy^{-1}}$, respectively. Although, Ethiopia has been a member of the international Atomic Energy Agency (IAEA) since 2011,

it does not yet have a radiation protection policy. Thus, the results of this study will be important as supportive materials for future to establish the country's common radiation safety guiderules policy for the case of radiation protection and assessments of the impact of radioactive hazards.

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Conflict of interests

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Data availability statement

Data associated with this article cannot be disclosed due to legal reason.

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