ASSESSMENT OF NATURAL RADIOACTIVITY IN SOIL SAMPLES AND TEA LEAVES AT GUMERO TEA FARM, ETHIOPIA

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Abstract. Naturally occurring radionuclide materials have been found in the Earth's surface. These radionuclides include uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). The natural radioactive material originated from the environment is the major source of radiation. The purpose of this work is to assess the specific activity of radionuclides in soil samples and tea leaves and to estimate the transfer factor of radionuclides from soil to tea leaves. The specific activity of natural radionuclides ^{238}U, ^{232}Th, and ^{40}K in six soil samples and tea leaves from Gumero tea farm were measured by gamma spectroscopy using a High Purity Germanium (HPGe) detector, and the radiological hazard parameters due to these natural radionuclides were determined. The mean specific activity of ^{238}U, ^{232}Th, and ^{40}K in soil samples were: 41.6 ± 1.4 Bq kg^{-1}, 81.8 ± 2.4 Bq kg^{-1}, and 184.8 ± 5.1 Bq kg^{-1}, respectively and for tea leaves they were: 3.5 ± 1.1 Bq kg^{-1} for ^{238}U, 4.9 ± 0.9 Bq kg^{-1} for ^{232}Th, and 516.7 ± 32.0 Bq kg^{-1} for ^{40}K. The average value of radium equivalent specific activity in soil samples was 172.0 ± 4.6 Bq kg^{-1} whereas, in tea leaves it was 53.3 ± 2.2 Bq kg^{-1}. This value is lower than the world average limit which is 370 Bq kg^{-1}. The mean absorbed dose rate (D_R) was found to be 26.1 ± 1.0 nGy h^{-1} and 76.3 ± 2.0 nGy h^{-1} in the tea leaves, and soil samples, respectively. The mean annual effective dose (*AED*) was 0.03 mSv y^{-1} and 0.09 mSv y^{-1} in tea leaves and soil samples, respectively. The mean external hazard index (H_{ex}) was 0.13 in the tea leaves and 0.46 in soil samples. The internal hazard index (H_{in}) was 0.16 in tea leaves and 0.57 in soil samples. These values are lower than the worldwide average limit which is 1. The mean value of absorbed dose rate in the soil sample is slightly higher than the world acceptable value but, on the other hand, the radiological hazard parameters for soil samples were lower than the recommended world average values. Therefore, from the radiological point of view, this study concludes that the soil and tea leaves at Gumero tea farm cannot caused any hazardous health effects to inhabitants by the consumption of Gumero tea.

Key words: Tea leaves, specific activity, dose rate, radium equivalent, HPGe, hazard index.

INTRODUCTION

Human beings are exposed to radioactivity every day from the ground, building materials, air, food, the universe, and even from the elements in their own

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body. People are exposed to low and high flow of radiation from artificial sources, too [33–35]. Naturally occurring radionuclide materials have been found on the Earth's surface. These radionuclides include ^{238}U, ^{232}Th, and ^{40}K [10].

The natural radioactive material originated in the environment is the major source of radiation. Natural radionuclides: ^{238}U series, ^{232}Th decay series, and the isotope of potassium (^{40}K) that are found in the surface of Earth, namely, in the rocks, the soil, building materials, water, air, food, and inside the human body [26], expose all living organisms. The half-lives time of radioactivity is long [6, 7, 15].

The sources of the background radiation in the environment are the radionuclides of primordial origin (^{40}K, ^{238}U, and ^{232}Th), the cosmogenic radionuclides (^{3}H, ^{7}Be, ^{12}C, ^{22}Na) [33], and the anthropogenic radionuclides (^{137}Cs, ^{90}Sr, ^{85}Kr). A recent study that was done in Ilubabour reported in [32] shows that 87 % of the radiation dose received by humankind is from the natural radiation of primordial and cosmogenic origin, and the remaining is due to human-made radiation. Public exposure to natural sources of radiation has been estimated by the [25] which concluded an effective average annual equivalent dose to 2.4 mSv y^{-1} per person [4].

The radioactivity in the agricultural land may be transferred to the plants [19]. from the soil through roots. When food plants are developed in polluted soil, the radioactivity is switched to the roots from the soil and then to the shoots [19]. In the end, it is transferred to the humans [2, 18].

Tea plants may be exposed to direct and indirect contamination of radionuclides from progenies of ^{238}U and ^{232}Th decay chains, or ^{40}K [32]. Radionuclides can also contaminate tea plants by radionuclide transfer from soil to plants through the roots [19, 32]. These radionuclides can be spread in different parts of the plants according to the chemical characteristics and parameters of the plants and soil [32].

Since tea is one of the frequently consumed beverages in the world, it is better to understand the effect of radionuclides found in tea leaves on humans. Therefore, this study has two targets. The first is to determine the specific activity of natural radioactivity levels in tea leaves and soil samples. The second is to determine the transfer factor of radioactivity from the soil to the tea leaves in Gumero tea plantations, in Western Ethiopia.

LITERATURE REVIEW

Naturally-occurring radioactive material (NORM) is the term used to describe materials containing radionuclides that exist in the natural environment [5]. The radionuclides uranium-238, uranium-235, and thorium-232 have been long-lived with their daughter products. ^{40}K, ^{87}Rb, and ^{115}In [20]. The half-lives of

parent radionuclides of ^{238}U, ^{232}Th, and ^{40}K are comparable with the age of the Earth. So, they have been found in the Earth's crust and within the tissues of all living species [5].

NORM is an expression generally used to refer to terrestrial radionuclides like ^{40}K, ^{232}Th, ^{238}U, and ^{235}U and their progeny decay products. These radionuclides are different from artificial radionuclides which do not exist in nature. Also, the term, TENORM refers to Technologically Enhanced Natural Occurring of Radioactive Material [20–21]. The term is used to classify any process done by human contact causing more concentration of NORM on the Earth's surface [16].

Humans are exposed to ionizing radiation from naturally occurring radioactive materials (NORM) [21]. They can interact with the human body through building materials, air, water, and food. They depend on the geological composition of the soil and rocks. Therefore, measurements of the radioactivity level in soils are important for understanding the natural radiation background as a function of geographical location and time [6, 7].

Radionuclides (U, Ra, Th, and K) are found in soil [30], their amount of radioactivity in soil depending on the type and different levels of the soil of each different geological regions [15]. Soil consists of minerals, organic matter, water, and air. These are an important element for development of plants. [15, 30]. The inorganic portion of the surface soils may fall into textural classes, depending on the percentage of sand, silt, and clay. Sand consists largely of primary minerals such as quartz with particle sizes ranging from 60 μm to about 2 mm [30]. Silt consists of particles in the range of 2 to 60 μm, while clay particles are smaller than 2 μm in diameter [5].

Plants are the primary recipients of radioactive contamination from the soil and the atmosphere [3]. Plants may be subject to direct and indirect contamination [32]. The direct contamination of terrestrial plants is the result of the deposition of radioactive materials from the atmosphere onto their leaves. Indirect contamination is due to the absorption of radionuclides from the soil by their root system [32]. Secondary recipients of food chain pollution are animals that eat plants or other animals. Both plant and animal products enter into the diet of humans [34, 35].

Soil-plant-man is a major track for the transfer of radionuclides to human beings [12, 16, 17]. The plants acquire deposited radionuclides from the soil. The soil-to-plant transfer factor (*TF*) is broadly used for estimating the radiological human dose via the ingestion pathway [11, 22].

The *TF* is one of the most important parameters in environmental safety assessment for nuclear facilities [17]. *TF* is essential for transfer models, which are useful in the prediction of radionuclide concentration in crops for estimating dose impact on human beings [14, 16–18, 31].

MATERIALS AND METHODS

The study was conducted in Gumero tea plantation which is located in the Ilubabour zone of the Oromia region of Southwest Ethiopia at about 637 km from the capital, Addis Ababa. The present size of the farm is 860 hectares. It is located at an altitude of 1,718 m above sea level and rainfall of 2,089 mm. The minimum and maximum temperatures are 12 °C and 24 °C, respectively. Its soil is fertile, has good drainage, red-brown color, and is rich in organic matter. In addition, Gumero has 761 hectares of eucalyptus trees planted to serve as fuel for tea drying in the factories [31–32].

Fig. 1 Location of the study area [32].

SAMPLE COLLECTION AND PROCEDURES

Soil samples

A total of six soil samples were collected from the Gumero tea farm. Each sample was taken at a depth of 25 cm and each was collected at a distance of 100 m apart at a randomly chosen points. The Global Positioning System (GPS) was used to record each sample and was marked by the number S1, S2, S3, S4, S5, and S6. The code and astronomical location of the sites are shown in Table 1. After the collection of samples, they were cleaned and dried into the sun and crushed into fine powder by using a grinder.

Tea leaves samples

A total of six tea leave samples were taken at six places and each was marked by TL1, TL2, TL3, TL4, TL5, and TL6. Then, they were dried by spreading in the air for about 4 days. The dried samples were ground to powder by using a grinder. All tea leave samples were added into the Marineli beakers and then sealed tightly with insulating tape around the opening of the containers to protect against contamination by air. Thereafter, the packed tea leaves were stored for 4 weeks to

achieve radiological equilibrium between ^{226}Ra and its daughter radionuclides. Finally, the specific activity of the radionuclides was evaluated in the radiation detection laboratory of the Ethiopian Radiation Protection Authority [1, 6, 7, 32]. The codes and the geographical location of soil samples and tea leaves are shown in Table 1.

Table 1

The code and astronomical locations of each soil sample and tea leaves

No. samples	Soil samples code	Tea leaves code	Geographical locations	
			Latitude N (deg)	Longitude E (deg)
Sample 1	S1	TL1	8.1452	35.4579
Sample 2	S2	TL2	8.1451	35.4575
Sample 3	S3	TL3	8.1450	35.4577
Sample 4	S4	TL4	8.1451	35.4575
Sample 5	S5	TL5	8.1451	35.4574
Sample 6	S6	TL6	8.1452	35.4570

High purity germanium gamma spectrometer (HPGe)

Gamma-ray is characterized by a high-energy and short wavelength within the electromagnetic spectrum [2, 6, 7, 9]. Gamma-ray spectrometry is an analytical method that allows the identification and quantifies of gamma-emitting isotopes in a variety of matrices [1, 6–8]. In a single measurement and with little sample preparation, gamma-ray spectrometry allows to detect several gamma-emitting radionuclides in the sample. In a spectrum of lines, the amplitudes is proportional to the specific activity of radionuclide shown by [1, 6, 7].

Specific Activity

The specific activity of ^{238}U, ^{232}Th, and ^{40}K of the samples were determined by standard gamma spectrometry using the HPGe detector (Ortec) with a relative efficiency of 70 % and a resolution of 1.9 keV for the 1332.5 keV ^{60}Co gamma line and MCA with 2000 channel [1, 6, 7, 32].

The background radiation and the samples were counted for about 345,600 s [3]. The 295.21 and 351.92 keV of ^{214}Pb and 609.31, 1120.29, and 1764.49 keV of ^{214}Bi gamma-ray lines were used to determine the specific activity of ^{238}U. The ^{232}Th specific activity was determined using 238.63 keV of ^{212}Pb, 911.21, and 968.97 keV of ^{228}Ac gamma lines [6, 7, 9, 32]. The specific activity of ^{40}K was determined directly from the 1460.8 keV gamma lines [9].

The specific activity is defined as activity per unit mass of the radioactive substance and is reported in units such as Curie per gram or Becquerel per kilogram (Bq kg^{-1}) [6, 7, 32]. The specific activity of radionuclides, mainly

^{40}K, ^{238}U, and ^{232}Th, were calculated by Genie-2000 software based on Eq. (1) reported in [6, 7, 9, 22]:

$$A = \frac{\frac{N_s}{t_s} - \frac{N_b}{t_s}}{\varepsilon(E_j) I \gamma M_s} \quad (1)$$

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

Radium equivalent activity (Ra_{eq})

To assess the activity concentration of materials that contain ^{226}Ra, ^{232}Th, and ^{40}K by a single quantity associated with the radium equivalent activity (Ra_{eq}) [6, 7]. This specific activity provides a guideline in regulating the safety standards on radiation protection. The radium equivalent activity represents a weighted sum of activities of ^{238}U, ^{232}Th, and ^{40}K. The radium equivalent activity is given by Eq. (2) reported in the [5–7, 31, 32]:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_U, A_{Th} and A_K are the specific activities of ^{238}U, ^{232}Th, and ^{40}K, respectively.

Absorbed dose rate

The absorbed dose rate is the amount of radiation energy deposited per unit of mass. It assesses the energy deposited in a medium by ionizing radiation per unit mass. The unit is J/kg and denoted by the equivalent S.I. unit, gray (Gy), or rad [6, 7]. The dose rate of gamma radiation is uniform near the surface of the ground. Therefore, the absorbed dose rate (D_R), in nGy h^{-1}, is calculated by the Eq. (3), reported in [5, 6, 32]:

$$D_R = 0.462A_U + 0.604A_{Th} + 0.417A_K \quad (3)$$

Annual effective dose equivalent

The annual effective dose equivalent (*AEDE*) received by individuals was calculated from the calculated values of D_R by applying the dose rate conversion factor of 0.7 Sv Gy^{-1} [6, 7] and the residence factors of 0.2

(5/24) and 0.8 (19/24) for outdoors and indoors, respectively. Therefore, the annual effective dose rate (mSv y^{-1}) was calculated by Eq. (4) [6, 7]:

$$AEDE\ (\text{mSv y}^{-1}) = D_R\ (\text{nGy h}^{-1}) \times 8760(\text{h y}^{-1}) \times 0.7(\text{Sv Gy}^{-1}) \times 0.2 \times 10^{-6} \quad (4)$$

Determination of radiation hazard indices

Many of the radioactive materials decay naturally and produce external radiation fields which expose humans. Regarding dose, the principal primordial radionuclides are ^{232}Th, ^{226}Ra and, ^{40}K [6, 7, 28, 29, 32]. Thorium and uranium series of radionuclides produced significant human exposure. The external hazard index (H_{ex}) is calculated by Eq. (5) [6, 7]:

$$H_{\text{ex}} = \frac{C_{\text{Ra}}}{370} + \frac{C_{\text{Th}}}{250} + \frac{C_{\text{K}}}{4810} \quad (5)$$

If the value of the external hazard index is less than unity then, the radiation hazard is insignificant.

The internal hazard index (H_{in}) of radionuclides is given by Eq. (6), according to [5, 6, 25]:

$$H_{\text{in}} = \frac{C_{\text{Ra}}}{185} + \frac{C_{\text{Th}}}{259} + \frac{C_{\text{K}}}{4810} \quad (6)$$

The index must be less than unity for the radiation hazard be considered negligible. Both the external and internal hazard indices are pure numbers, and they do not have dimensions [2, 12, 27].

Gamma index

Gamma index I_γ was evaluated with the Eq. (7) to estimate the radiation hazard associated with the natural radionuclide [6, 7]. The values of $I_\gamma \leq 1$ Bq kg^{-1} correspond to an annual effective dose of less or equal to 1 mSv [6, 7].

$$I_\gamma = \frac{A_{\text{U}}}{300} + \frac{A_{\text{Th}}}{200} + \frac{A_{\text{K}}}{3000} \quad (7)$$

Excess lifetime cancer risk

Excess lifetime cancer risk (*ELCR*) depends on the exposure level rates during the lifetimes of human beings [6, 7, 11]. A higher value of *ELCR* implies a higher probability of cancer induction to the exposed individuals. It can be calculated using the following Eq. (8), according to [6, 7]:

$$ELCR = AEDE \times DL \times RF \quad (8)$$

where *AEDE* is the annual effective dose equivalent, the duration of life (*DL*) is the duration of life (estimated to be 70 years) [6, 7] and *RF* (in Sv^{-1}) is the risk factor [6, 7, 11]. For the stochastic effects, the International Commission on Radiological Protection (ICRP) uses *RF* as 0.05 for the general public ICRP [6, 7, 18]. *ELCR* is higher than the world permissible value of 0.29×10^{-3} [16, 35].

Determination of transfer factor of radionuclide from soil to plant

The soil-plant-man is the main path to transfer radionuclides to human beings. The soil-to-plant *TF* is regarded as one of the most important parameters in environmental safety assessment for nuclear facilities [3, 17]. TF is used for the prediction of radionuclides in crops which are transferred from soil to leaves [3, 17, 30]. It is used for estimating dose impact on a human being [3, 16, 30]. The soil-to-plant *TF* measures the transfer of radionuclides from soil to plant taken by the plant roots according to [3, 17]. From the observed activity concentrations of the radionuclide in the plant and in the corresponding soil, the *TF* values were calculated according to Eq. (9) [17, 30]:

$$TF = \frac{\textit{Specific activity of radionuclide in plants}\ \ (\mathrm{Bq\,kg^{-1}\ dry\ weight})}{\textit{Specific activity of radionuclide in soil}\ \ (\mathrm{Bq\,kg^{-1}\ dry\ weight})} \tag{9}$$

RESULTS AND DISCUSSION

RESULTS

Soil samples from Gumero tea plantation

As it was already said, the purpose of this work is to find the specific activities of ^{238}U, ^{232}Th, and ^{40}K soil samples collected from Gumero tea plantations.

The spectrum of soil samples

The gamma-ray spectra from all the soil samples were analyzed, taking into account the peak centroid energy of interest from the ^{238}U and ^{232}Th decay chains, and also from ^{40}K. Daughter radionuclides from the decay chains in the samples were identified by comparing their gamma-ray energies with known energies from the published references.

The gamma-ray spectrum of soil sample 1 (S1N) shown in Table 1, is shown in Figure 2, in which each detected gamma energy line of the radionuclides was labeled on the spectrum with gamma counter per channel. The vertical axis refers to the gamma counter per channel.

In the spectrum shown in Figure 2, the gamma-ray transitions associated with the decay of ^{238}U and ^{232}Th parent nuclei are noted. These include ^{214}Pb and ^{214}Bi

from the uranium series and ^{212}Pb and ^{228}Ac from the thorium series. ^{40}K at 1460.81 keV gamma-energy, is also observed in the samples [15].

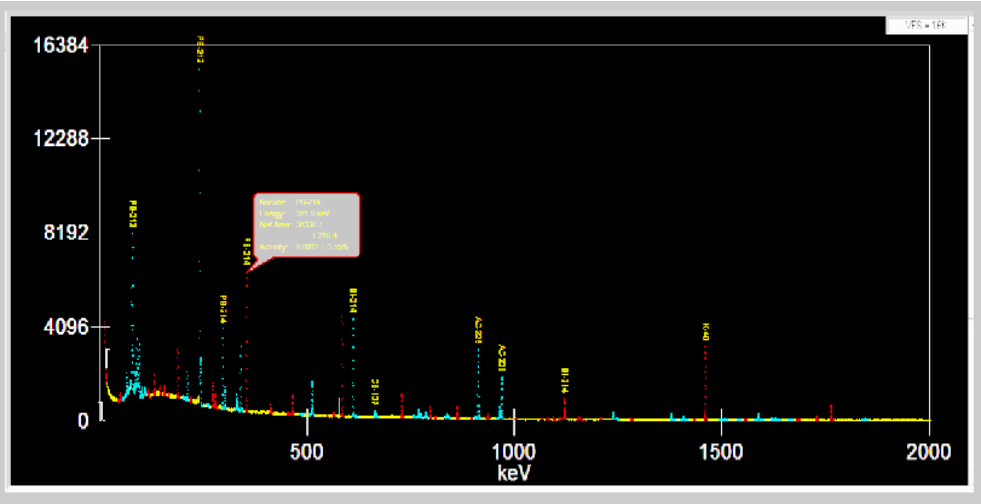

Fig. 2. Gamma-rays spectrum for soil sample 1 (S1N).

The specific activity of the detected radionuclides in soil samples

The specific activity of the samples adopted on the lead isotope (^{214}Pb) at energies of 295.21 and 351.92 keV, bismuth (^{214}Bi) at energies of 609.31,1120.29 and 1764.49 are equivalent to the specific activity of uranium (^{238}U) by choosing the highest value of their activities. While the specific activity adopted on the lead isotope (^{212}Pb) at energies of 77.1 and 238.63 keV and actinium (^{228}Ac) at energies of 911.21 and 968.97 keV, respectively are equivalent to the specific activity of thorium (^{232}Th) by choosing the highest value of their activities. The specific activity of the concentrations of radionuclides ^{40}K have been calculated by using the energy 1460.81 keV. The specific activity of the concentration of radionuclides can also be determined using Eq. (2). The calculated specific activity concentrations of natural radionuclides in soil samples are presented in Table 2.

The specific activity is shown in Table 2 ^{238}U, ^{232}Th, and ^{40}K in soil samples was varied from 37.0 ± 1.3 Bq kg^{-1} to 46.2 ± 1.4 Bq kg^{-1}, 61.3 ± 1.7 Bq kg^{-1} to 123.4 ± 2.1 Bq kg^{-1}, and 149.2 ± 4.6 Bq kg^{-1} to 216.6 ± 5.1 Bq kg^{-1} respectively with a mean of 41.6 ± 1.4 Bq kg^{-1}, 81.8 ± 2.4 Bq kg^{-1}, and 184.8 ± 5.1 Bq kg^{-1}, respectively. The maximum specific activities were observed in the first sample S1N of the soil, ^{238}U, ^{232}Th, and ^{40}K are 46.2 ± 1.4 Bq kg^{-1}, 123.4 ± 2.1 Bq kg^{-1}, and 216.6 ± 5.1 Bq kg^{-1} respectively. While the minimum specific activity was observed for ^{238}U, ^{232}Th, and ^{40}K are 37.0 ± 1.3 Bq kg^{-1}, 61.3 ± 1.7 Bq kg^{-1}, and 149.2 ± 4.6 Bq kg^{-1}.

Table 2

The measured specific activity of natural radionuclides in soil samples

Sample Code	The specific activity (Bq kg^{-1})		
	^{238}U	^{232}Th	^{40}K
S1N	46.2 ± 1.4	123.4 ± 2.1	216.6 ± 5.1
S2N	45.0 ± 1.5	83.7 ± 2.3	197.9 ± 5.1
S3N	37.0 ± 1.3	86.0 ± 1.6	191.1 ± 5.7
S4N	45.4 ± 1.5	73.5 ± 2.6	204.0 ± 5.5
S5N	38.6 ± 1.4	63.0 ± 2.1	150.3 ± 4.7
S6N	37.3 ± 1.3	61.3 ± 1.7	149.2 ± 4.6
Minimum	37.0 ± 1.3	61.3 ± 1.7	149.2 ± 4.6
Maximum	46.2 ± 1.4	123.4 ± 2.1	216.6 ± 5.1
Mean	41.6 ± 1.4	81.8 ± 2.4	184.8 ± 5.1
World Average	30.0	35.0	400.0

Radiological hazard parameter in soil samples

One of the main objectives of the radioactivity measurement in an environmental sample is not only to determine the activity of ^{238}U, ^{232}Th, and ^{40}K in given samples but also to estimate the radiation exposure dose and to assess the biological effects on human beings. To assess the health effects, the radiation hazard parameters such as radium equivalent activity (Ra_{eq}), absorbed dose rate (D_R), effective dose rates (*AED*), external hazard index (H_{ex}), internal hazard index (H_{in}), annual gonad dose, excess lifetime cancer risk, and gamma index have been calculated by using Eqs. (3–8) from the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K. The results of the analysis of the radiological hazard parameter indices in soil samples are presented in Table 3.

The values of radium equivalent (Ra_{eq}) are shown in Table 3, column 2. The radium equivalent for the soil samples from the study area was varied from 136.4 ± 3.7 Bq kg^{-1} to 239.2 ± 4.8 Bq kg^{-1} with an average of 172.2 ± 4.6 Bq kg^{-1}. The absorbed dose rates are shown in Table 3, due to these radioactive nuclides in soil samples have been found to vary from 60.5 ± 1.8 n Gy h^{-1} to 104.8 ± 2.1 nGy h^{-1} with an average value of 76.3 ± 2.0 nGy h^{-1}. The annual effective dose equivalent has been calculated from 0.07 mSv y^{-1} to 0.13 mSv y^{-1} with an average value of 0.09 mSv y^{-1}.

The obtained value of excess lifetime cancer risk varied from 0.25 to 0.44 (dimensionless) with the mean of 0.32, this value being slightly higher than the world average limit of excess lifetime cancer risk, which is 0.29.

Table 3

Radiological hazard parameters in soil samples

Sample code	Ra_{eq} (Bq kg^{-1})	D_R (nGy h^{-1})	*AEDE* (mSv y^{-1})	H_{ex}	H_{in}	I_γ	*ELCER* 10^{-3}
S1	239.2 ± 4.8	104.8 ± 2.1	0.13	0.65	0.77	0.84	0.44
S2	179.7 ± 5.2	79.5 ± 2.3	0.10	0.5	0.6	0.63	0.34
S3	174.7 ± 4.0	77.0 ± 1.8	0.10	0.47	0.57	0.61	0.33
S4	163.2 ± 5.6	74.0 ± 2.5	0.10	0.40	0.57	0.58	0.31
S5	140.3 ± 4.5	62.0 ± 2.0	0.08	0.37	0.48	0.5	0.26
S6	136.4 ± 3.70	60.50 ± 1.80	0.07	0.36	0.47	0.48	0.25
Minimum	136.4 ± 3.7	60.5 ± 1.8	0.07	0.36	0.47	0.48	0.25
Maximum	239.2 ± 4.8	104.8 ± 2.1	0.13	0.65	0.77	0.84	0.44
Mean	172.2 ± 4.6	76.30 ± 2.0	0.09	0.46	0.57	0.6	0.32
World AVG value	370.0	60.0	0.48	1.00	1.00	1.00	0.29

TEA LEAVES FROM GUMERO PLANTATION

The specific activity of the detected radionuclides in tea leave samples is shown in Table 4.

Table 4

Specific activity of radionuclides in tea leave samples

Sample ID	The specific activity (Bq kg^{-1})		
	^{238}U	^{232}Th	^{40}K
TL1	5.4 ± 0.3	6.8 ± 1.3	664.1 ± 1.2
TL2	1.6 ± 0.3	5.7 ± 0.9	533.6 ± 3.1
TL3	5.6 + 0.1	3.7 ± 0.8	459.7 ± 2.1
TL4	1.9 ± 0.5	3.8 ± 0.8	457.5 ± 20.1
TL5	5.2 + 0.1	4.6 ± 1.0	454.6 ± 1.0
TL6	1.1 ± 0.2	5.0 ± 0.8	530.8 ± 30.1
Minimum	1.1 ± 0.2	3.7 ± 0.8	454.6 ± 1.0
Maximum	5.6 ± 0.1	6.8 ± 1.3	664.1 ± 1.,3
Average	3.47 ± 1.13	4.93 ± 0.92	516.69 ± 32
World AVG	35.00	30.00	400.00

Table 4 shows that the specific activity of ^{238}U in tea leave samples was ranged from 1.1 ± 0.2 Bq kg^{-1} to 5.6 ± 0.1 Bq kg^{-1} with an average value of 3.5 ± 1.1 Bq kg^{-1}. The average value of ^{238}U specific activity is lower than the recommended maximum value of 35 Bq kg^{-1} [28, 35]. The specific activity of ^{232}Th of the tea samples was ranged from 3.68 ± 0.76 Bq kg^{-1} to 6.8 ± 1.3 Bq kg^{-1} with an average of 4.9 ± 0.9 Bq kg^{-1}. Moreover, Table 4 shows the specific activity of

^{40}K which varies from 454.6 ± 1.0 Bq kg^{-1} to 664.1 ± 1.3 Bq kg^{-1} with an average value of 516.7 ± 32.0 Bq kg^{-1}.

Radiological hazard parameters in the tea leave samples

The calculation of radiation hazard indices such as radium equivalent activity (Ra_{eq}), absorbed dose rate (D_R), gamma index ($I\gamma$), annual effective dose equivalent ($AEDE$), external hazard index (H_{ex}), internal hazard index (H_{in})] in tea leave samples were determined as it was reported in the [3] and is shown in Table 5.

Table 5

The radiological hazard parameters indices in fresh tea leave samples

Sample code	Ra_{eq} (Bq kg^{-1})	D_R (nGy h^{-1})	$AEDE$ (mSv y^{-1})	H_{ex}	H_{in}	I_γ	$ELCER$ 10^{-3}
TL1	66.2 ± 2.0	34.3 ± 0.9	0.04	0.18	0.19	0.27	0.14
TL2	50.8 ± 1.8	26.4 ± 0.8	0.03	0.13	0.14	0.21	0.11
TL3	46.3 ± 1.2	24.0 ± 0.5	0.03	0.12	0.14	0.19	0.10
TL4	42.6 ± 3.1	22.3 ± 1.5	0.03	0.11	0.12	0.17	0.09
TL5	46.8 ± 1.5	24.2 ± 0.7	0.03	0.12	0.14	0.19	0.10
TL6	49.0 ± 3.6	25.6 ± 1.8	0.03	0.13	0.13	0.20	0.10
Minimum	42.6 ± 3.1	22.3 ± 1.5	0.03	0.11	0.12	0.17	0.09
Maximum	66.2 ± 2	34.3 ± 0.9	0.04	0.18	0.19	0.27	0.14
Average	53.3 ± 2.2	26.1 ± 1.0	0.03	0.13	0.16	0.20	0.10

The values of radium equivalent activity (Ra_{eq}) in tea leaves samples shown in Table 5, column 2 was varied from 42.6 ± 3.1 Bq kg^{-1} to 66.3 ± 2.0 Bq kg^{-1} with an average of 53.3 ± 2.2 Bq kg^{-1}. The absorbed dose rate is shown in Table 6, column 3 the tea leaves sample has been found to vary from 22.3 ± 1.5 nGy h^{-1} to 34.3 ± 0.9 nGy h^{-1} with an average value of 26.1 ± 1.0 nGy h^{-1}. The annual effective dose equivalent shown in Table 5, column 4 was between 0.03 to 0.04 mSv y^{-1} with an average value of mSv y^{-1}. Both the external and internal hazard indices values are shown in column 5, and are ranged from 0.11 to 0.18 with a mean of 0.13 and from 0.12 to 0.19 with a mean of 0.16, respectively. The values of the gamma index shown in column 7 are ranged from 0.17 to 0.27 with an average of 0.20. The excess cancer risk shown in column 8 is ranged from 0.09 × 10^{-3} to 0.14 × 10^{-3} with an average value of 0.10 × 10^{-3}.

Transfer factor of radionuclide from soil to tea leaves

Plants are contaminated by radiation in two ways: by absorption of radionuclide from the soil by their roots and by depositions of radionuclides on their leaves. Our consideration is only on uptake of radionuclide from soil to leave. The Table 6 shows the values of the transfer factor of radionuclides from soil to tea leaves.

Table 6

Transfer factor of radionuclide from soil to tea leave

Specific activity of ^{238}U (Bq kg^{-1})			Specific activity of ^{232}Th (Bq kg^{-1})			Specific activity of ^{40}K (Bq kg^{-1})		
Soil	Tea leaves	*TF* in tea leaves	Soil	Tea leaves	*TF* in tea leaves	Soil	Tea leaves	*TF* in tea leaves
46.2 ± 1.0	5.4 ± 0.3	0.18	123.3 ± 2.0	6.7 ± 1.3	0.05	216.6 ± 5.0	664.1 ± 1.3	3.06
45.0 ± 1.5	1.6 ± 0.3	0.03	83.6 ± 2.3	5.7 ± 0.9	0.07	197.9 ± 5.1	53.6 ± 3.1	2.69
37.0 ± 1.0	5.6 ± 0.1	0.15	86.0 ± 1.6	3.7 ± 0.7	0.04	191.1 ± 5.7	459.6 ± 2.1	2.40
45.4 ± 1.5	1.9 ± 0.2	0.04	73.5 ± 2.6	3.8 ± 0.7	0.05	204.0 ± 5.5	457.5 ± 20.0	2.24
38.6 ± 1.4	5.2 ± 0.1	0.14	63.0 ± 2.1	4.6 ± 1.0	0.07	150.3 ± 4.7	454.0 ± 1.0	3.02
37.3 ± 1.3	1.1 ± 0.2	0.03	61.3 ± 1.7	5.0 ± 0.8	0.08	149.2 ± 4.6	530.8 ± 3.0	3.55

The transfer factor of radionuclides from soil to tea leave is calculated by applying Eq. (9) [3]. The transfer factor of ^{238}U was found to be 0.03 to 0.1 shown in Table 6, that of ^{232}Th from soil to tea leave was ranged from 0.042 to 0.08 and the transfers factor of ^{40}K is ranging from 2.24 to 3.55.

DISCUSSIONS

The specific activity is shown in Table 3 for ^{238}U, ^{232}Th, and ^{40}K in soil samples and varied from (37.0 ± 1.3) Bq kg^{-1} to (46.2 ± 1.4) Bq kg^{-1}, 61.3 ± 1.7 Bq kg^{-1} to 123.4 ± 2.1 Bq kg^{-1}, and 149.2 ± 4.6 Bq kg^{-1} to 216.6 ± 5.1 Bq kg^{-1} respectively with a mean of 41.6 ± 1.4 Bq kg^{-1}, 81.8 ± 2.4 Bq kg^{-1}, and 184.8 ± 5.1 Bq kg^{-1}, respectively. The mean specific activity concentration of ^{238}U was higher than the recommended world average value. This value is also higher than the specific activity of ^{238}U in the soil of Harar, and the soil of Dire Dawa city [6, 7, 23] respectively. The specific activity of ^{238}U in soils of Zuwaye is lower than the specific activity measured in this work [27, 35].

The mean specific activity of ^{232}Th in this work was higher than the world average limit and also higher than in the soils of Harar, and the soil of Dire Dawa city [6, 7, 23]. While the activity concentration of ^{40}K was below the world average limit [35]. This value was lower than the earlier reports of specific activity of 40K in the soil samples of Harar, Dire Dawa city, and the soil of Zuwaye which are [5–7, 23, 27]. The worldwide average recommended values of ^{238}U, ^{232}Th, and ^{40}K are 30, 35, and 400 Bq kg^{-1} respectively reported in the [25, 33–35].

The annual effective dose equivalent is obtained in this work is less than the worldwide average limit shown by [32]. The calculated values of the external and internal hazard indices are ranged from 0.36 to 0.65 with a mean of 0.46 and from

0.47 to 0.77 with a mean of 0.57, respectively. Both are lower than unity that keeps the radiation hazard acceptable [19]. The values of the gamma index ranged from 0.48 to 0.84 with an average of 0.6. This value is lower than the international acceptable values of the gamma index which is [6, 7].

The average value shown in Table 3 of Raeq is far below the internationally accepted value [8, 32, 35]. The absorbed dose rate shown in Table 4 are higher than the world average limit of absorbed dose shown in [19, 22–24].

The specific activity of ^{238}U is obtained in this work is lower than the earlier report of specific activity of ^{238}U in tea samples collected from Bangladesh [24], and the tea samples collected from the local market in Ethiopia [32]. The result obtained in this work, the average value of 232Th is lower than the worldwide acceptable value ^{232}Th reported in [35]. This value is also lower than the specific activity of ^{232}Th in the tea samples of Bangladesh and Ethiopia reported in [24, 32]. The specific activity of ^{40}K is found in this work are higher than the allowable value of ^{40}K which is 400 Bq kg^{-1} but lower than the specific activity of ^{40}K which is obtained from tea samples from the local market in Ethiopia reported in [32].

The present findings were compared with the results reported in previous studies. In this regard, the specific activities of radionuclides obtained in this work was greater similar result obtained in Iran [27]. Similarly, the specific activities of radionuclide obtained in Egypt were comparable to this works [15]. Also, the specific activities of radionuclides obtained in Turkey agree with this work [13].

The average calculated value of Ra_{eq} shown in Table 3 is far below the internationally accepted value which is 370 Bq kg^{-1} [32, 35]. The mean effective dose rate of 0.01 mSv y^{-1} measured in Gumero soil samples is lower than the world average limit [19]. The absorbed dose rate in Gumero soil samples is slightly greater than the world average limit as it was reported [19]. The annual effective dose limit agrees with the worldwide average limit of annual effective dose limit which is 1 mSv y^{-1} [32]. Both the internal and hazard indexes, found in this work, are lower than unity; that keeps the radiation hazard acceptable [6, 7].

CONCLUSIONS

In this study, the specific activity of natural radionuclide concentration, namely ^{238}U, ^{232}Th, and ^{40}K for the soil samples and tea leaves were determined and the associated radiological hazard parameters were carried out. The specific activity values obtained in this work for of ^{238}U and ^{232}Th, and ^{40}K in the soil samples are slightly higher than the world average limit. The mean value of absorbed dose rate in the soil sample is slightly higher than the world acceptable value but the other radiological hazard parameters for soil samples were lower than the recommended world average values.

From the radiation protection point of view, this study concludes that the soil at the Gumero tea farm cannot cause any hazardous health effects to inhabitants and the consumption of Gumero tea is safe. The level of radionuclides in tea leaves was lower than the standard limits set by international organizations. The uptake of ^{40}K by tea leaves is higher than those for other two places, Dire Dawa and Harar city. Even though the leave uptake of ^{40}K is greater than the international limit, we can conclude that the activity level of tea samples is non-threatening to public health.

The data of this study will provide a good baseline for setting standards quality in Ethiopia tea now and future. The data obtained in this study may also, be useful for natural radioactivity mapping of Gumero area.

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