ESTIMATION OF ANNUAL EFFECTIVE RADIATION DOSE AND CANCER RISK DUE TO TEA CONSUMPTION

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https://www.doi.org/10.59277/RJB.2024.2.02

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Abstract. The current study aims to assess the radioactive health risks and their levels due to tea consumption. Fresh tea leaves were plucked from different locations in the Gumero tea farmland in Ilubabour zone, Ethiopia. High-resolution gamma-ray spectroscopy was used to measure the activity concentrations of artificial and natural radionuclides (*e.g*., ^{40}K, ^{232}Th, and ^{238}U) in the samples. Radiological indicators such as committed dose rate (D_R) and excess lifetime cancer risk, *LCR* (*i.e*., the cancer death risk due to lifetime exposure to carcinogens, ignoring the contribution of natural background risk) were evaluated to ascertain the radioactive risk to humans in the tea samples. D_R and *LCR*, two radiological markers, were assessed to determine the radioactive risk to humans in the tea samples. The finding shows that the radiological hazards assessment of ^{238}U and ^{232}Th revealed that the Gumero tea leaves have natural radioactivity levels within the internationally recommended limit, while that of ^{40}K was higher than the limit. Comparing the current study with other studies, it was found that the yearly effective doses and nuclide radioactivity concentrations in tea leaves were similar.

Key words: Risk, lifetime, cancer, hazard, dose, tea.

INTRODUCTION

In our world, tea is one of the most popular drinks. About 75 % of the estimated 2.5 million metric tons of dry tea produced annually are common black teas [21]. Tea is a beverage prepared from leaves. Hot or cold tea continues to be the most widely consumed drink in the world. Scientific investigations on the chemical structure of tea and leaves have been carried out from different angles, including environmental, toxicological, and therapeutic ones.

Asia produces 90 % of the world's tea, which is grown in more than 40 countries. However, little is known about the environmental effects of heavy metals on tea plantations or how the plants themselves absorb them. Depending on the kind (black or green) and the tea's geological origin, the metallic content of tea leaves often varies [2].

Received: January 2024;
in final form January 2024.

Human activity is the source of artificial radionuclides, regularly in agriculture, medicine, research, and other closely connected mining industries [10]. Radiation is released by the production of synthetic radionuclides by the decay of naturally occurring radionuclides. It has been demonstrated that these nuclides could cause cancer in living beings. The known additional aspect to take into account is their radioactive concentration in food [10].

“Background radiation” refers to radiation originating from both artificial and natural radiation. The variance in background radiation levels is determined by the concentration of radioactive elements in the rock and surrounding soil.

Radiation exposure may present long-term health risks, such as an increased risk of cancer, depending on its actual level [10, 20, 25]. The public is becoming increasingly concerned about the cumulative radiation exposure by tea drinking, especially for children. They are very likely to experience health problems later in adult life. A chronic radiation dose can fall into one of two categories from the outside or the inside [32].

Radiation contamination of food and soil can be used to assess radiation exposure levels both within and outside the body, according to [28]. Radioactivity activity, for example, can be used to calculate the quantity of radiation internally and externally inhaled. The amount of radiation ingested internally can be ascertained from the meal [26].

Because of the soil and tea leaves at the farm, previous research that assessed the increased lifetime cancer risk connected with the tea leaves found no evidence of harm to the locals' health from ingesting Gumero tea [4]. The other radiological hazard metrics for soil samples were lower than what was suggested by world average values. However, the mean value of the absorbed dose rate in the soil sample is somewhat higher than the globally acceptable value [4].

Researchers who studied tea leaves over the past few years have documented the discovery of radioactive different brands [14, 15, 18, 32]. Measurements from *in situ* gamma-ray spectrometry were used in this investigation to calculate the increased lifetime cancer risk. Thus, appraising the additional lifetime cancer risk in children, teenagers, and adults is the goal of this effort.

MATERIALS AND METHOD

STUDY AREA

The Gumero tea farm, positioned in the Ilubabour district in Ethiopia's southwest, some 637 kilometers from Addis Ababa, served as the study's site. At the moment, 860 hectares make up the farm. The coordinates of the tea farm are 8.14^{o} latitude and 35.52^{o} longitude [4, 23, 27].

DATA COLLECTION

Ten tea leaf samples were taken from the farm at six separate points, and the sample codes L1–L10 were used to identify each sample. They were then left to dry in the outdoors for around four days. The dried ingredients have been ground into powder. All of the tea leaf samples were carefully placed into the Marineli beakers. The aperture of the containers was sealed with insulating tape to avoid contamination from the air. The tea samples were stored for 45 days at the original location in the Laboratory of Environmental Analysis and Computational Simulation (LAASC) monitoring the radionuclide activities to meet the secular radioactive equilibrium criteria.

Gamma-ray spectrometry measurements and the computation of the increased lifetime cancer risk due to radioactive materials were conducted in Dire Dawa [1, 4, 6]. ^{238}U and its offspring radionuclides reach a radiological equilibrium as a result of the naturally occurring radioactivity in tea leaves.

Finally, the Ethiopian Radiation Protection Authority's radiation detection laboratory assessed the specific activity of the radionuclides [1, 5, 6].

DOSE ESTIMATION

The specific concentration (Bq kg^{-1}) could be used to calculate the compromised effective dose (μSv y^{-1}) and the yearly effective dose rate. It makes use of the intake (D_i) transfer factor proposed by [11], whose values were adjusted for these purposes. The effective dose for each tea sample was investigated using the equation:

$$D_R = D_i \times T_i \times A_i \tag{1}$$

where D_R, according to [10], is the yearly effective dose rate (μSv y^{-1}). D_i is the dose coefficient (μSv Bq^{-1}), A_i is the specific radionuclide concentration in the tea (Bq kg^{-1}), and T_i is the amount of tea ingested in a year (kg). Ethiopians consumed, in 2012, 20 g of sugar a day per adult according to data from the Central Statistics Agency (CSA) and the World Food Program (WFP) [3].

It was considered conceivable that, throughout the infusion process, all radionuclides might be transmitted to tea. These statistics aid in the comprehension and application of the annual dose calculation.

Table 1

The dose coefficients according to [9]

Radionuclide	Dose coefficient (D_i) (μSv Bq^{-1})
^{238}U(^{226}Ra)	280.0
^{232}Th	690.0
^{40}K	6.2

The effective dose rate mentioned in Eq. (2) can be written in the following for

$$D_{\mathrm{R}} = 0.461A_{\mathrm{U}} + 0.623A_{\mathrm{Th}} + 0.0414A_{\mathrm{K}} \quad (2)$$

where the coefficients: 0.461, 0.623, and 0.0414 (nGy h^{-1})/(Bq kg^{-1}) are the conversion factors for ^{238}U, ^{232}Th, and ^{40}K, respectively.

The external and internal hazard indexes were calculated to make sure that radiation exposure due to ^{238}U, ^{232}Th, and ^{40}K in the analyzed samples was within the allowable dose equivalent of 1 mSv y^{-1} [4, 8, 19]. Eq. (3) is used to determine the external hazard index, H_{ex}:

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

Annual effective dose (*AEDE* [mSv y^{-1}]) was computed to estimate the health effects of the absorbed dose, which was calculated by using the Eq. (4).

$$AEDE = D_{\mathrm{R}}\left(\frac{\mathrm{nGy}}{\mathrm{h}}\right) \times 8760\left(\frac{\mathrm{h}}{\mathrm{y}}\right) \times 0.2 \times 0.7\left(\frac{\mathrm{Sv}}{\mathrm{Gy}}\right) \times 10^{-6} \quad (4)$$

A study evaluated the cancer risk associated with tea consumption because longer life spans are associated with higher radiation exposure levels. The US Environmental Protection Agency suggested a method for calculating lifetime cancer risk is given by Eq. (5), according to [30].

$$LCR = AEDE \times A \times CR \quad (5)$$

where *LCR* stands for lifetime cancer risk, annual radionuclide intake (Bq), *A* is an average lifetime (68.29 years old in Ethiopia), and *CR* is the cancer risk coefficient (Bq^{-1}), in that order. According to statistics [33], the cancer risk coefficient for ^{226}Ra is 9.56×10^{-9} (Sv^{-1}) 2.45×10^{-9} (Sv^{-1}) for ^{232}Th, and 5.89×10^{-10} (Sv^{-1}) for ^{40}K. Cancer risks are categorized as minimal below 10^{-6} and severe enough above 10^{-4}.

By combining Eqs. (3)–(5), we can express the *LCR* by Eq. (6) as:

$$LCR = 0.14 \times H_{\mathrm{ex}} \times A \times 10^{-6} \quad (6)$$

where *A* is the average lifespan of the humans.

RESULTS AND DISCUSSIONS

RESULTS

The radionuclides in the tea leaf sample were the source of the radioactive background radiation in Ilubabour, Ethiopia. Many naturally occurring radionuclides extracted from farming soil are present in tea. The particular activity of ^{238}U, ^{232}Th, ^{40}K, annual effective inhalation doses, and excess lifetime cancer of the tea are all determined by this work

The average values of natural radionuclide activity concentrations of ^{40}K, ^{232}Th, and ^{238}U, in tea from Gumero farms are displayed in Table 2 and Figures 1 and 2. Table 2 shows the specific activity of the radioactive elements that were collected in the research region together with the values of the radiological risk factors that were computed using these values, including the minimum, maximum, average, and standard deviation. The specific activity of ^{238}U ranged from 1.1 ± 0.2 to 12.45 ± 0.2 Bq kg^{-1} with an average of 5.22 ± 3.26 Bq kg^{-1}. Similarly, the specific activity of ^{232}Th ranged from 3.7 ± 0.8 to 23.54 ± 0. 1.5 Bq kg^{-1} with an average of 8.29 ± 6.13 Bq kg^{-1}. On the other hand, the specific activity of ^{40}K ranged from 454.6 ± 1.0 to 664.1 ± 1.2 Bq kg^{-1} with an average of 552.47 ± 78.65 Bq kg^{-1}.

Table 2

The specific activity of tea leaves from Gumero farm ^{226}Ra, ^{232}Th, and ^{40}K

Sample code	Specific activities [Bq kg^{-1}]		
	^{238}U	^{232}Th	^{40}K
L1	5.40 ± 0.30	6.8 ± 1.30	664.10 ± 1.20
L2	1.60 ± 0.30	5.70 ± 0.90	533.60 ± 3.10
L3	5.60 ± 0.10	3.7 ± 0.80	459.70 ± 2.70
L4	1.90 ± 0.10	3.80 ± 0.80	457.50 ± 20.50
L5	5.20 ± 0.20	4.60 ± 1.00	454.60 ± 1.00
L6	1.10 ± 0.20	3.70 ± 0.80	530.80 ± 30.15
L7	4.70 ±0.10	8.76 ± 1.30	567.87 ± 14.50
L8	7.50 ± 0.20	12.54 ± 0.60	623.45 ± 3.50
L9	6.75 ± 0.10	9.76 ± 0.90	587.34 ± 4.50
L10	12.45 ± 0.20	23.54 ± 1.50	645.70 ±12.50
Min	1.10 ± 0.20	3.70 ± 0.80	454.60 ± 1.00
Max	12.45 ± 0.20	23.54 ± 1.50	664.10 ± 1.20
Average	5.22	8.29	552.47
Std.	3.26	6.13	78.65

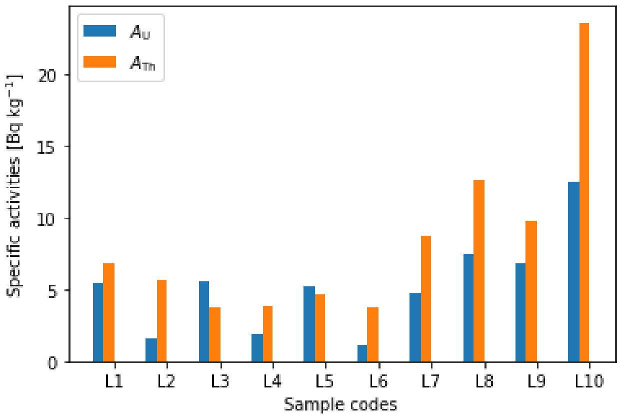

Fig. 1. Specific activities of ^{238}U and ^{232}Th of tea leaves collected from Gumero farm.

Figure 1 displays the particular activity of ^{238}U and ^{232}Th in each sample. It demonstrates that L10 had the highest value. Similarly, Figure 2 displays the precise tasks completed by ^{40}K in each location. Sample L1 had the highest specific activity of ^{40}K, ^{232}Th, and ^{238}U.

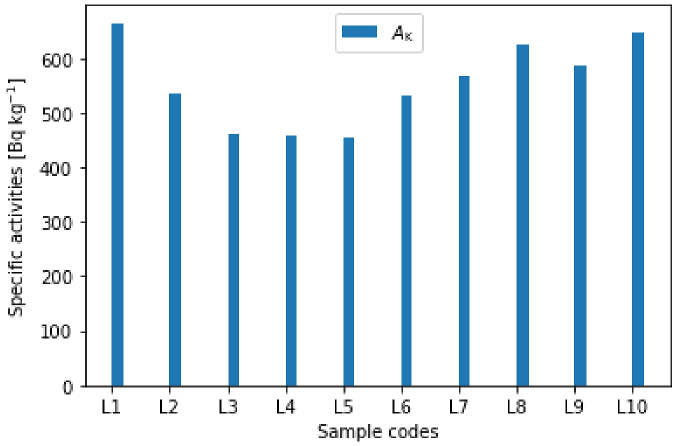

Fig. 2. The specific activity of ^{40}K radionuclides of tea leaves.

Figures 3 and 4 display relationships between specific activities of ^{238}U, ^{232}Th, and ^{40}K. Figure 3 shows the linear interactions and empirical correlations between A_{Th} and A_U. The linear connection is $A_{Th} = 1.61A_U - 0.115$, with an RMSE of 0.78.

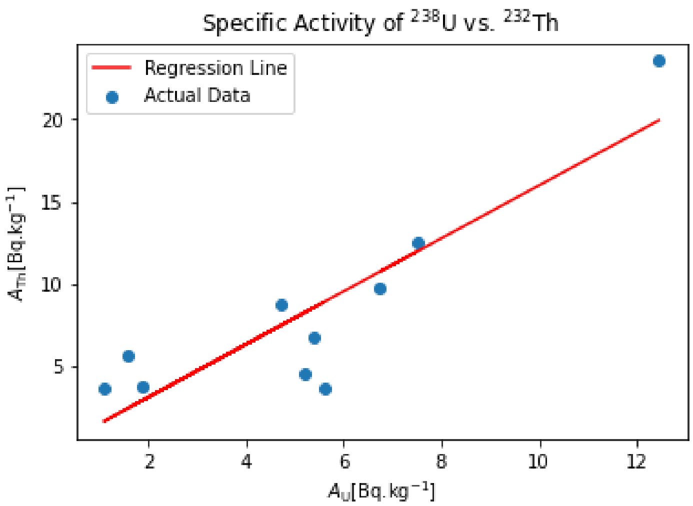

Fig. 3. The specific activity of ^{232}Th vs. ^{238}U whose relation is given by $A_{Th} = 1.61A_U - 0.115$ with root mean square error (RMSE) 0.78.

The empirical correlations and linear relationships between ^{238}U and ^{40}K are shown in Figure 4 and are as follows: ^{40}K has an RMSE of 0.32 and $A_{Th} = 13.23\ A_U + 483.41$. There are linear correlations between A_U and A_{Th}, with a high correlation coefficient, according to scattering data from Gumero farmlands. On the other hand, it is evident from the coefficient association the data in A_U / A_{Th} connections are better distributed along the line. Based on the correlation coefficient and the lessened data dispersion around the line, it can be concluded that the radioactive elements are more linear than the in A_U / A_{Th}.

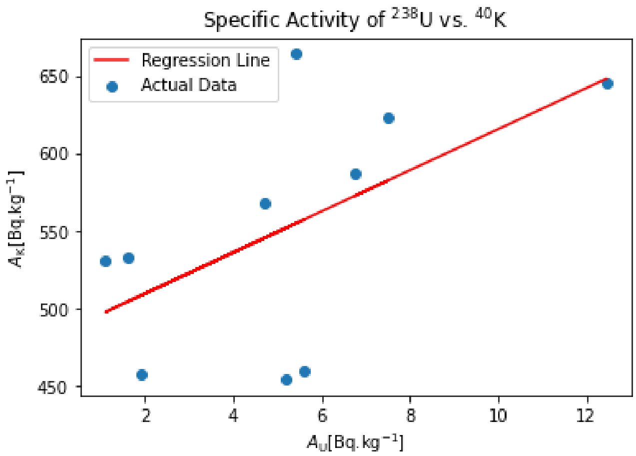

Fig. 4. The specific activity of ^{40}K vs. ^{238}U whose relation is given by $A_K = 13.23\ A_U + 483.41$, and $r^2 = 0.32$. It was considered that 1 L of liquid tea has a mass of 1 kg.

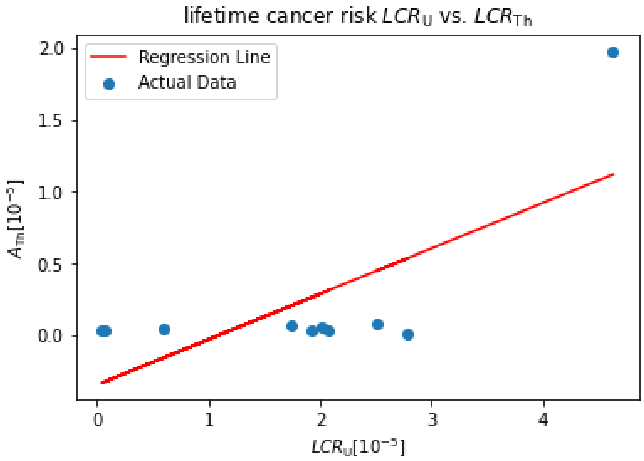

Fig. 5. Excess lifetime cancer of adults due to ^{232}Th vs. that of ^{238}U whose relation is given by $LCR_{Th} = 0.316\ LCR_U - 0.344$ and $r^2 = 0.51$ of tea leaves from Gumero farm for adults.

The correlations between the specific activity and the lifetime cancer are depicted in Figures 5 and 6. Figure 5 shows the linear relations between A_U and A_{Th}, whereas the relationships between radioactive elements and the excess lifetime cancer risk are given by LCR_{Th} = 0.316 LCR_{U} – 0.344 is the linear equation that describes their relationship. Equation LCR_{K} = 0.0018 LCR_{U} + 0.0083 illustrates the correlations between potassium and uranium shown in Figure 6. Furthermore, the correlation coefficient between increased lifetime cancer risk, potassium, and thorium was found to be 0.53 and 0.51, respectively, using the root mean square (RMS) method.

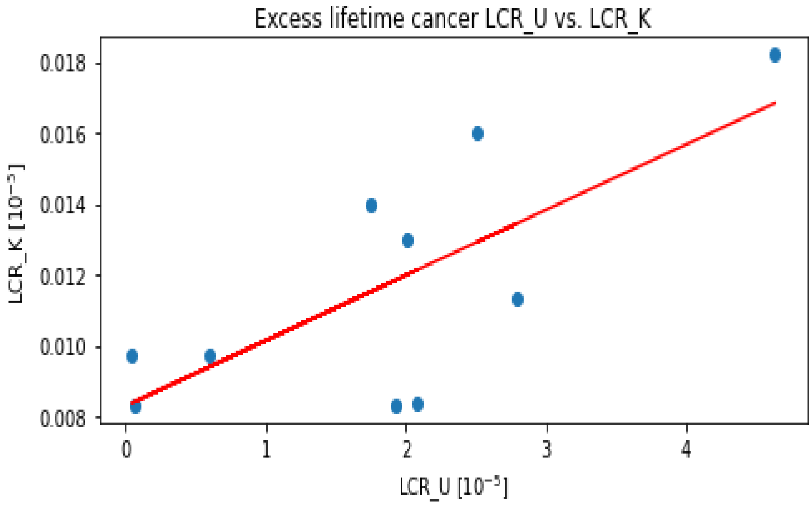

Fig. 6. Excess lifetime cancer of adults due to ^{40}K vs that of ^{238}U. whose relation is given by LCR_{K} = 0.0018 LCR_{U} + 0.0083 and r^2 = 0.53 of tea leaves from Gumero farm for adults.

Table 3 displays the cancer risk associated with radionuclides ^{40}K, ^{232}Th, and ^{238}U. Using Eq. 6, its parameter was computed. This parameter illustrates the impact of the radiation risk parameter on human health. According to [12, 13], the following factors were taken into account to determine the minimum/maximum and average lifetime cancer risk estimates for Gumero tea leaves: The range of *LCR* was 2.46 to 1.109 with an average of 1.553×10^{-6} for 70 years adults; 0.161 to 0.362 with an average of 0.225×10^{-6} for 45 years adults; 0.290 to 0.652 with an average of 0.406×10^{-6} for 18 years young people; and 0.724 to 1.630 with an average of 1.014×10^{-6} for 10 years children.

The increased lifetime cancer risk for each age group is shown in Figure 7. The findings indicate that adults are more likely to be exposed to cancer risk than the other groups. Although their bodies are not as strong as those in the other groups, children in the young category have a slightly lower cancer exposure rate.

Table 3

The lifetime cancer risk (*LCR*) due to ^{238}U, ^{232}Th, and ^{40}K from tea leaves collected from Gumero farmland using Eq. 6

Sample code	Lifetime cancer risk (10^{-6}) based on ages			
	Life expectancy (70)	Adults (45)	Youth (18)	Children (10)
L1	1.726	0.250	0.451	1.127
L2	1.324	0.192	0.346	0.865
L3	1.206	0.175	0.315	0.787
L4	1.109	0.161	0.290	0.724
L5	1.219	0.177	0.318	0.796
L6	1.231	0.179	0.322	0.804
L7	1.588	0.230	0.415	1.037
L8	1.913	0.278	0.500	1.249
L9	1.717	0.249	0.449	1.122
L10	2.496	0.362	0.652	1.630
Min	2.496	0.362	0.652	1.630
Max	1.109	0.161	0.290	0.724
Average	1.553	0.225	0.406	1.014
Std.	0.430	0.062	0.112	0.281

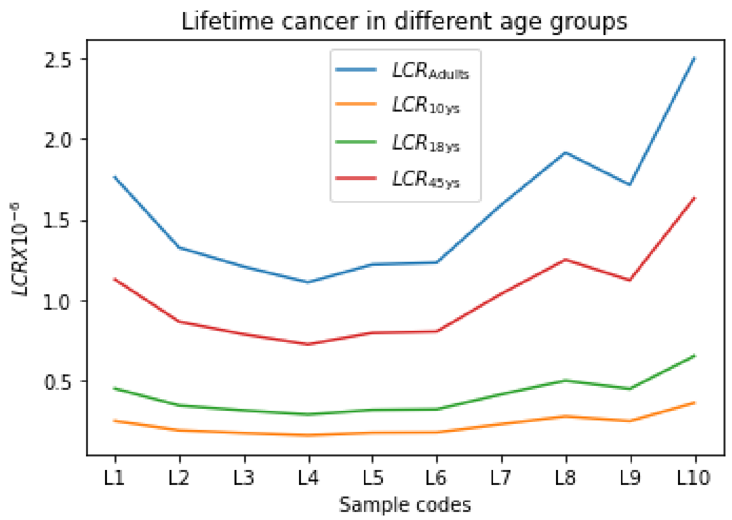

Fig. 7. The lifetime cancer risk of tea leaves from Gumero tea farms.

DISCUSSIONS

The specific activities of ^{238}U, ^{232}Th, and ^{40}K levels were reported in other studies, especially when compared with studies from Bangladesh, Egypt, Iran, Indonesia, and Saudi (Table 4). In tea samples, the activity of ^{238}U ranged from 1.8 $\pm$ 0.6 to 4.3 $\pm$ 1.0 Bq kg^{-1}, and the mean activity was 3.1 $\pm$ 0.7 Bq kg^{-1}. In Egypt, the activity was lower than in this study. Similarly, the specific activity of ^{232}Th was lower than in this study, whereas the specific activity of ^{40}K was higher than in Egypt [9]. In addition, the activity concentration measurements of ^{40}K surpass the international limit threshold, of 400 Bq kg^{-1} [7, 8]. The ability of these plants to absorb potassium and other elements from the soil may explain their higher potassium activity. The observed activity concentrations of ^{238}U, ^{232}Th, and ^{40}K found in tea samples varied in Bangladesh being lower than the values shown in Table 3 [16, 17]. The present finding of radionuclide-specific activities is moderate and below the limits of the international as shown in Table 4 [29].

It is noted that the average excess lifetime cancer for ten-year-old children was lower than for adults shown in Table 3. Excess lifetime cancer due to ^{238}U leave sample L1 was higher than the other samples. But it was lower than the international limits [33].

Table 3 shows the mean excess cancer lifetime risk that defines the probability that people who consumed tea in their lifetime can develop cancer. The result shown in Figure 7 indicates that the average lifetime cancer risk due to ^{238}U, ^{232}Th, and ^{40}K for adults were 1.841×10^{-5}, 2.39×10^{-6}, and 1.2×10^{-6} for adults whose life expectancy was 70 years old. Their values are lower than the world average *LCR* safe limit of 0.344×10^{-3} [8].

Table 4

Comparison of specific activities of green tea leaves plucked from Gumero tea farmlands

County	Specific Activity [Bq·kg^{-1}]			References
	^{238}U	^{232}Th	^{40}K	
Egypt	3.1 ±0.7	4.8± 0.8	623.0±25.0	[16]
Bangladesh	5.34 ±0.38	10.07 ±0.83	430.0± 35,5	[14]
Nigeria	3.75 ±0.69	7.86±1.72	45.46± 3.57	[27]
Indonesia	16.951	1.427	45.036	[18]
Saudi	7.25± 0.54	7.78±0.63	471.40± 11.33	[21]
Ethiopia	5.22± 3.26	8.29± 6.13	552.47±78.65	This study

These findings are consistent with the body of research that shows tea drinking is safe in terms of cancer risk [30–32]. It's crucial to remember that this result only applies to the circumstances and settings this study looked at. It might take further investigation and continuous observation to fully comprehend the wider health effects of tea consumption.

CONCLUSIONS

In Ethiopia's western region, the Ilubabour Zone, tea is a prominent and beneficial plant that is radioactively exposed. The goal of this study was to assess the intrinsic radioactivity of ten tea samples collected from Gumero tea plantations, which produce the most popular and commonly consumed tea. We found correlations between activities of radioactive elements (^{40}K, ^{238}U, and ^{232}Th), present in the tea leaves, and the increased lifetime cancer risk.

According to this study, drinking tea does not enhance one's lifelong cancer risk. As a result, the study's conclusions are comforting because they show no evidence of a lifelong cancer risk increase linked to tea use. The findings indicate that, for this analysis, tea can be regarded as a safe beverage about cancer risk.

Based on the findings of this study, consumers should feel confident in maintaining their tea-drinking habits.

Acknowledgment: We are deeply grateful to the Ethiopian Radiation and Protection Agency for providing us with the low background counting laboratory and its research facilities. The corresponding author acknowledges the financial support provided by the Department of Physics at Dire Dawa University to finish this research project on schedule.

Declaration of competing interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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