Environmental Radioactivity evaluation and its health-related effects using gamma spectrometry in Delanta-Dawunt, Wollo District, Ethiopia

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Abstract
Background & Methodology: The specific activity concentration of naturally occurring radionuclides $^{226}$Ra, $^{232}$Th, $^{40}$K and their health related effects were determined in different environmental samples(gemstones) collected from Delanta-Dawunt. Which is one of the mining place in Ethiopia to extract mainly opals (gemstones). Sample collection and the gamma spectroscopic analysis followed the recommended international procedures for such type of research. Gamma-ray spectrometry was applied using HPGe gamma-ray detector and PC-based MCA.

The Purpose of this research: to determine the activity concentrations of the radionuclides U/Th series and K of gemstones(opals), to determine life time cancer risk of radionuclide in the environment , to assess the hazard and risk to the public associated with these dose values , to conduct the geochemical studies by quantifying the levels of trace gemstones as well as the physical parameters in soil samples within and around it, and To determine the radiation doses from these activity concentrations and compare with international recommended dose limits.

Results: The results of the activity concentration on our research work showed significant variations from $11.97 \pm 2.46$ to $62.44 \pm 14.99$ Bq kg$^{-1}$ for $^{226}$Ra, $25.69 \pm 3.69$ to $137.84 \pm 13.23$ Bq kg$^{-1}$ for $^{232}$Th and $184.84 \pm 3.59$ to $969.56 \pm 18.16$ Bq kg$^{-1}$ for $^{40}$K. The mean radioactivity concentration of $^{226}$Ra, $^{232}$Th, and $^{40}$K was found to be around $29.84 \pm 6.53$, $68.44 \pm 18.94$, $390.87 \pm 6.09$ Bk kg$^{-1}$ respectively.

Conclusion: The mean values of Radium equivalent activity (Raeq), absorbed dose, annual effective dose equivalent, external and internal radiation hazard (Hex and Hin) index ,and activity utilization index is $151.68\pm19.46$ Bq kg$^{-1}$, $72.19 \pm 8.48$ nGy h$^{-1}$, $0.07 \pm 0.01$ mSv y$^{-1}$, $0.43$, $0.51$, $0.57 \pm 0.08$ and $0.29 \pm 0.03$ respectively. The specific activity of $^{222}$Th is higher than the world mean value and $^{40}$K is the same as the world mean value. The radiation hazard indices, ELCR values found in this study are lower than the world mean values. However, the absorbed dose is higher than the world means value. This is due to the reason of high thorium concentration existence and opal mining is highly explored on such study areas.
1 Introduction

Heat and light are the types of radiation that peoples can feel and see, and therefore the two have been recognized as “elements” of the universe for a long time. Contrary to this, its prime “element”, radioactivity, which results in radiation that human sense cannot detect, was been discovered only a century ago.

Although radiation has found applications in almost all aspects of human activities, most of the ionizing radiation that people are exposed to still comes from natural sources. The health effects of radiation are relatively well understood and can be effectively minimized through careful safety measures and practices.

Radioactivity is a part of nature in the process of element formation by the nuclear reaction taking place in stars, both stable and radioactive isotopes of elements are formed. The earth and atmosphere contain varying levels of radiation from naturally occurring radionuclides. Soil features, geological formations, and human practices resulting in radiation emissions are important factors enhancing the levels of background natural radiation [1,2].

Natural radioactivity present in soil produces gamma radiations in the environment and changes the background radiation level. Everyone on the planet is exposed to these background levels of ionizing radiation. External exposure occurs as a result of irradiation and internal exposure because of inhalation and ingestion [3].

Mining activities and the processing of natural resources have impacted considerably on human being and the environment [4,5]. Mining operations are associated with environmental degradation, destruction of ecosystems and and general pollution of the environment [5,6]. Huge amounts of top soils are removed during mining which results in the production of considerable amount of mining wastes (tailings) with enhanced radioactivity [7]. These large quantities of mine tailings are disposed of on the surface in the vicinity of the mine where they are subjected to continuous physical, chemical and biological processes that concentrates radioactivity in the environment, resulting in significant radiation dose to the public [8]. Mine tailings consists of relatively loose non-compacted debris that easily contaminate the surrounding soils through atmospheric dispersion. The dust particles suspended in the air can also be inhaled directly, thus contributing to human radiation exposure [9,10].

The isotopic composition of elements is characterized by properties of nuclear reactions that led to the formation of the elements. The elemental composition of the planet earth thought to be about $4.5 \times 10^9$ years old, although not yet in chemical equilibrium, reflects the composition of the material from which it was formed. Therefore, several radionuclides occur in nature, having long half-lives (longer than the age of the earth) [11].

Numerous sources of ionizing radiation can lead to human exposure: natural sources, nuclear explosions, nuclear power generation, use of radiation in medical, industrial, and research purposes, and radiation-emitting consumer products [12].

The sources of radiation that contribute to this rate are of natural origin (cosmic radiation, radionuclides of the U and Th series, Radon and Thoron and K-40) and artificial (fall-out of nuclear explosions in the earth crust, Chernobyl accident, the release of radioisotopes in nuclear facilities, use of radioactive sources in industries and nuclear medicine radiopharmaceuticals). Another source, which may be growing in recent years, is TENORM also contributes to the increase in dose in occupationally exposed workers [13]. $^{238}$U is present in traces in most soil and rocks and it decays to $^{228}$Ra, which is the parent of $^{222}$Rn. The radium content of soil and rocks is responsible for the radon concentration in the ground [14,15]. Before assessing the radiation dose to the population, one requires precise knowledge of the activity of several radionuclides. Radioactive nuclei that are found in air, soil, and water either naturally, or as a result of human activities make up what is called background radiation. According to UNSCEAR estimates the global average human exposure from natural radiation sources is 2.4 mSv y$^{-1}$, and 82 % of this amount is attributed to the natural sources of terrestrial and cosmic origin [15].

Furthermore, radiation exists everywhere on the earth's crust and exposure from natural background radiation is the largest component of total radiation exposure received by most people. The measurement of gamma radiation dose from environmental sources is of significance because the radiation of natural origin is the principal contributing factor to the non-internal dose globally. The activity concentrations of radionuclides in the environment vary according to the geological formation; radionuclides in rocks are easily mobilized into the environment through natural and human processes [16].
2 Methodology and method

2.1 Sample collection and preparation

In this paper, the natural radioactivity levels in the gemstone soil samples of Delant-Dawunt areas are calculated by gamma-ray spectroscopy using an HPGe 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 gemstones soil samples will provide awareness among them about the radiological effects on their health. Each gemstone's soil and rock sample were collected from different areas and was marked carefully cleared of debris, organic residue, and stone fragments to a few centimeters’ depths. Each gemstone soil and rock sample was packed in a plastic bag and labeled according to the geographical coordinates of the sampling area.

The collected gemstones soil/rock sample were weighted and dried for 24 hours in an oven at 105 °C in the polymer laboratory at Addis Ababa University. Then the dried sample was crushed in an automatic grinder in the geology laboratory in this university. And then, they were sieved with a 0.25mm mesh to keep uniform grain size and obtain a fine-grained homogeneous gemstones soil/rock sample for measurements. About 500g of the homogenized gemstones soil/rock samples were packed and sealed in an airtight Marinelli beaker and stored for one month to reach secular equilibrium among the daughter product of $^{226}\text{Ra}$, and their short-lived decay products. The gamma analysis was done at the Ethiopian Radiation Protection Agency laboratory.

![Sampling areas](image-url)

Fig1. sampling areas are taken from a satellite image of a google map
2.2 Calibration and Gamma Spectrometry Measurements

The gamma-ray system (Canberra coaxial hyper pure germanium detector) has a photopeak efficiency of 30% and energy resolution of 1.8 keV full-width at half maximum (FWHM) for the 1332 keV gamma-ray line of $^{60}$Co. A model B13010 detector was a shield with lead has a 0.040 in and 0.062 in the copper graded liner to prevent interference by lead X-rays. The detector operating voltages around 3499V and Genie 2000 software from Canberra were used to analyze the spectra. The calibration of the spectrometer was carried out by using standard point sources ($^{60}$Co, $^{137}$Cs). An empty bottle with the same geometry was measured for subtracting the background. The counting time was about 28,800 s to obtain the gamma spectrum with good statistics. The gamma-ray transitions of energies 295.21 and 351.92 keV ($^{214}$Pb), 609.31 keV, 1120.29 keV, and 1764.49 keV ($^{214}$Bi) and were used to determine the concentration of the $^{238}$U/$^{226}$Ra decay series. The gamma-ray transitions of energies 338.4 keV, 911.21 keV, and 968.97 keV ($^{228}$Ac), 583.3 keV ($^{208}$Tl), were used to determine the concentration of the ($^{232}$Th) series. The 1460.81 keV gamma-ray transition $^{40}$K was used to determine the concentration of $^{40}$K in different samples.

3 Radiological Parameters

The calculated activity of thorium, uranium, and potassium of 8 samples collected from in Delantadawunt on different lithological units of the study are plotted in figure 1 (sample area). From the collected samples of such area radionuclides detected mostly belong to the $^{232}$Th, $^{238}$U/$^{226}$Ra decay series, though the most prominent gamma-ray energy peak, observed corresponding to $^{232}$Th.

3.1 Natural radionuclides in environmental samples

Using the dry weight of the samples, the net counts ($N_c$), detector photo-peak efficiency ($\varepsilon_\gamma$) of the peak under consideration, the probability of the transition of the radionuclide of interest at the respective gamma energy ($P_\gamma$) the mass (m) of the sample in kg and the sample counting time (s) using Equation (1) [17, 18, 19, 20], their respective specific activity of NORM could be expressed (Bq kg$^{-1}$)

$$A = \frac{N_c}{M \varepsilon_\gamma P_\gamma t}$$  \hspace{1cm} (1)

The calculated specific activity of $^{232}$Th, $^{226}$Ra, and $^{40}$K are indicated in Table 1.

| Sample Code | Activities (Bq kg$^{-1}$) | Radium equivalent (Bq kg$^{-1}$) | Absorbed Dose (nGyh$^{-1}$) | Annual effective dose equivalent (mSv y$^{-1}$) |
|-------------|--------------------------|---------------------------------|-----------------------------|-----------------------------------------------|
|             | $^{226}$Ra | $^{232}$Th | $^{40}$K | Ra$_{eq}$ | D | AEDE |
| ABBS        | 62.44±14.99 | 137.84±13.23 | 374.31±5.96 | 262.44±34.36 | 128.64±14.89 | 0.16±0.01 |
| AGS         | 18.25±4.08  | 45.43±5.98  | 280.81±5.48 | 104.83±13.05 | 48.17±5.70  | 0.06±0.01 |
| BBS         | 61.58±11.29 | 115.99±18.03 | 398.85±0.12 | 258.08±37.09 | 115.67±16.06 | 0.14±0.02 |
| GOS         | 16.03±2.77  | 25.69±3.69  | 969.59±18.1 | 127.44±9.45  | 64.55±4.26  | 0.08±0.01 |
| KOK         | 11.97±2.46  | 27.31±3.94  | 184.8±3.59  | 65.26±8.36   | 30.08±3.66  | 0.04±0.01 |
Table 1. Results of specific activity, radium equivalent activity, and radiological hazards in different soil and rock samples of the Delanta-Dawunt area.

|                | Specific Activity | Radium Equivalent Activity (Ra\text{eq}) | Radiological Hazards |
|----------------|-------------------|----------------------------------------|----------------------|
|                | (Bq kg\textsuperscript{-1}) | (Bq kg\textsuperscript{-1}) | (Bq kg\textsuperscript{-1}) |
| Ghana Medicinal plant | 31.8±2.8 | 56.2±2.3 | 839.8±11.9 | No information [17] |
| Sapin Soil | 25 | 31 | 615 | No Information [18] |
| Qatar Soil & building materials | 17.22 ±1.55 | 6.38 ±0.26 | 169 ±5 | 40.6±7.4 [19] |
| Nigeria Rock | 13.1±1.6-129± 38 | 42.4±4.5-150 23 | 64.5±6.3-882± 298 | 83-391 [16] |
| Egypt Granitic rock | 5.26 - 336.70 | 3.12 -64.43 | 160.22-774.16 | 40.26-465.26 [23] |
| Ethiopia Soil | 19.97±2.42 | 56.38±4.50 | 716.59±68.43 | No information [24] |

1 The activity of a radioactive source or radionuclide sample is, by definition, its strength or intensity, or in other words, the number of nuclei decaying per unit time. The activity of a given radionuclide in a sample is proportional to the number of radioactive atoms present in that sample.
| Country             | Material            | Dose (nGy/h) | Dose (μSv/h) | Dose (mSv/h) | Radium Equivalent (μSv/h) |
|---------------------|---------------------|--------------|--------------|--------------|---------------------------|
| Ethiopia            | Flouri culture soil | 142.29±27.67 | 7.82 ± 0.54  | 259.62 ± 44.9 | 140.42±9.81               |
| India               | Flooring materials  | 25.48        | 42.82        | 560.69       | 130.29                    |
| Brazil(Mambucaba)   | Sand                | 169          | 963          | 824          | 669                       |
| Iraq                | Soil                | 34.8         | 18.8         | 289.2        | 83.95                     |
| Turkey              | Soil                | 27.1         | 34.3         | 370.5        | No information            |
| Turkey              | Soil                | 167          | 44           | 404          | 258                       |
| Malaysia            | Soil                | 3798±419     | 12896±1533   | 2521±298     | No information            |
| Cyprus              | Soil & rock         | 14.2±5.7     | 10.6±5.1     | 153±5.6      | No information            |
| Nigeria             | Soil                | 47.06±14.01  | 75.97±9.11   | 216.02±62.37 | 172.33                    |
| Ethiopia            | Gemston Soil/rock   | 29.84±6.53   | 68.44±18.94  | 390.87±6.09  | 151.68±19.46              |
| World average       |                     | 35           | 30           | 400          | 370                       |

Table 2 comparison of activity concentration and radium equivalent of different samples from different countries of the world

Dose rate and annual outdoor effective dose

External absorbed dose rate (D) in the air is defined for terrestrial gamma radiation at a height of about 1m above the ground [27].

\[
D(nGy/h) = 0.427A_{Ra} + 0.623A_{Th} + 0.043A_{K} \quad (3)
\]

In the present study, the absorbed dose for the different locations of gemstone soil and rock samples varied from 30.08 ± 3.66 to 128.64 ± 14.89 with a mean value of 72.19 ± 8.48, which is higher than the world mean value of 57nGy/h [32].
Annual outdoor effective dose (AEDE)

The measurement of the concentrations of radionuclides in the environment due to terrestrial gamma radiation from $^{238}\text{U}/^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$, can be estimated by the average outdoor conversion coefficient from absorbed dose rate in the air and the environmental gamma dose conversion factor (CC) to be 0.7 Sv/Gy to convert the absorbed dose ratio to the annual effective dose equivalent. Besides, when a person spent 20% outdoor occupancy factor (OOF) of 0.2 and the time was exposed to gamma rays during a year ($T$) is $8760$ h / y [28, 29, 33].

\[
\text{AEDE} (\mu\text{Sv/y}) = D \times \text{CC} \times \text{OOF} \times T 
\]

The world average annual effective dose equivalent to outdoor terrestrial gamma radiation is $70$ (\(\mu\text{Sv y}^{-1}\)). From Table (1), the annual effective dose equivalent (mSv\(^{-1}\)) range from $0.04 \pm 0.01$ to $0.16 \pm 0.01$ with a mean value of $0.07 \pm 0.01$ mSv\(^{-1}\). It is the same as the world average value.

External Hazard Index (Hex)

Every human being is continuously exposed to an external radiation field produced by natural radionuclides coming from soil, sediments, and rocks. To assess this issue, the external radiation hazard index is defined on the basis that the radiation exposure due to natural radionuclides should not surpass the permissible dose equivalent limit [16, 30, 33].

\[
H_{\text{ext}} = \frac{A_{\text{Ra}}}{370} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4810} \leq 1
\]  \hfill (5)

The value of this index must be less than unity to keep the radiation hazard insignificant. The prime objective of this index is to limit the radiation dose to the accepted dose limit of $1\text{mSv/y}$ [35].

Internal hazard index ($H_{\text{int}}$)

Inhalation of alpha particles emitted from the short-lived radionuclides (radon, $^{222}\text{Rn}$, the daughter product of $^{226}\text{Ra}$) and thoron ($^{220}\text{Rn}$, the daughter product of $^{224}\text{Ra}$) is also hazardous to the respiratory organs. This hazard can be controlled by the internal hazard index ($H_{\text{int}}$) which is given by [31]

\[
H_{\text{int}} = \frac{A_{\text{Ra}}}{185} + \frac{A_{\text{Th}}}{259} + \frac{A_{\text{K}}}{4810} \leq 1
\]  \hfill (6)

For the safe use of certain building material in the construction of dwellings, the index ($H_{\text{int}}$) should less than unity.

External ($\gamma$ radioactivity) level index ($I_{\gamma}$)

This index is also known as a representative level index and was calculated from the following relation [26, 36]

\[
I_{\gamma} = \frac{A_{\text{Ra}}}{300} + \frac{A_{\text{Th}}}{200} + \frac{A_{\text{K}}}{3000} \leq 1
\]  \hfill (7)
The OECD group of experts suggested some criteria for a definition of different levels of to be (representative, first enhanced, secondly enhanced).

\[ I_{\gamma} = 1 \] as an upper limit, \( I_{\gamma} \leq 1 \) corresponds to 0.3mSv/y, \( I_{\gamma} \leq 3 \) corresponds to 1mSv/y.

**Internal (\( \alpha \) radioactivity) level index \( I_\alpha \)**

The excess alpha radiation due to radon inhalation originating from building materials is estimated using the relation below [37]

\[
I_\alpha = \frac{A_{Ra}}{200} \leq 1
\]  
(8)

It should be lower than the maximum permissible value of \( I_\alpha \leq 1 \), which corresponding to 200Bqkg\(^{-1}\).

For alpha radiation and taking into consideration that a building material with \(^{226}\text{Ra}\) concentration less low than 200 Bqkg\(^{-1}\) could not cause indoor radon concentration higher than 200Bqm\(^{-3}\).

| Samples | \( H_{\text{ext}} \) | \( H_{\text{int}} \) | \( I_{\gamma} \) | \( I_\alpha \) | ELCR(mSv y\(^{-1}\)) |
|---------|------------------|------------------|----------------|--------------|------------------|
| ABBS    | 0.78             | 0.95             | 1.02±0.12      | 0.31±0.08    | 0.51±0.03        |
| AGS     | 0.28             | 0.33             | 0.38±0.14      | 0.09±0.02    | 0.19±0.02        |
| BBS     | 0.69             | 0.86             | 0.92±0.13      | 0.31±0.06    | 0.46±0.06        |
| GOS     | 0.34             | 0.39             | 0.51±0.03      | 0.08±0.01    | 0.26±0.02        |
| KOK     | 0.18             | 0.21             | 0.24±0.03      | 0.06±0.01    | 0.12±0.02        |
| ROS     | 0.25             | 0.29             | 0.33±0.04      | 0.08±0.02    | 0.17±0.02        |
| CWS     | 0.46             | 0.52             | 0.61±0.07      | 0.12±0.03    | 0.31±0.04        |
| Mean value | 0.43             | 0.51             | 0.57±0.08      | 0.15±0.03    | 0.29±0.03        |

\(^2\)Table 3 result of radiological hazards index for different soil and rock samples of Delanta-Dawunt

\(^2\)Any radiation exposure might have negative effects on health. This can be considered as the basic principle of radiation protection. The biological effect of ionizing radiation is a consequence of the energy transfer by ionization and excitation to body cells. The radiosensitivity of tissue is directly proportional to the reproductivity of cells it is made of (mitosis) and inversely proportional to the differentiation of the cells.
Excess lifetime cancer risk (ELCR)

Here, the AEDE is the annual effective dose equivalent, the average life expectancy of DL (average 67 years), and the risk factor for RF, and for stochastic effects, ICRP risk factors for lethal cancer in the whole population, respectively (1/Sv), RF ICRP 103, BEIR VII [23] (NRC, 2006) and for ICRP 60, 0.057, 0.064 and 0.072 are used [38, 39].

ELCR (mSv/y) = AEDE × DL × RF

Here, the AEDE is the annual effective dose equivalent, the average life expectancy of DL (average 67 years), and the risk factor for RF, and for stochastic effects, ICRP risk factors for lethal cancer in the whole population, respectively (1/Sv), RF ICRP 60, 0.072 are used.

4 Results and Discussion

The results of activity concentration of 238U-series, 232Th-series, and 40K radionuclides in gemstone rock/soil samples from eight sites in the Delanta-Dawunt are presented in Figs. 1 and also Table 1 shows the activity concentrations of 226Ra, 232Th, and 40K respectively. The range of the measured activity of 226Ra in the gemstone rock/soil samples was 11.97 ± 2.46 to 62.44 ± 14.99 with an average value of 29.84 ± 6.53 Bq kg⁻¹ which is lower than the world average value.

The minimum value of 226Ra was obtained in the sample of code KOK and a maximum for the sample of code ABBS. The differences are attributable to the geochemical composition and origin of gemstone soil types in a particular area. The range of measured activity the concentration of 232Th for the gemstone rock/soil samples was 25.69 ± 3.69 to 137.84 ± 13.23 Bq kg⁻¹ with an average value of 68.44 ± 18.94 Bq kg⁻¹ which is higher than the world average values. The minimum value obtained in sample code ABBS and a maximum for the sample code GOS. The differences are significant in all samples. The range of the activity concentration of 40K was in the 184.8 ± 3.59 and 969.59 ± 18.16Bq kg⁻¹, with an average value of 390.87 ± 6.09 Bq kg⁻¹ which is approximately the same as the world average value. These differences are also attributable to the gemstone soil type differences in the region under investigation besides the gemstones(opals) exploration. Moreover, our obtained average values fall within the range of corresponding world values and other published results [15] mentioned in Table 2. The world average activity concentration of 226Ra is 35 Bq kg⁻¹ with ranges of 17 to 60 Bq kg⁻¹, 232Th is 30 Bq kg⁻¹ with ranges of 11 to 64 Bq kg⁻¹ and 40K is 400 Bqkg⁻¹ with ranges of 140 to 850 Bq kg⁻¹ [15; 40]. The observed results in some samples show that the activity concentrations for 226Ra 232Th and 40K for the investigated sites are higher than the reported international radioactivity levels of 226Ra and 232Th in [15,40]. The recorded high values of the radionuclides in some soil samples may be due to the presence of radioactive rich granite, phosphate, sandstone, and quartzite. The activity concentration of thorium is higher than radium in all samples in this study as shown in Table 1 and Fig 2.

The activity concentration of 226Ra in this study is higher than Spain [18], Turkey [29], Nigeria [16], Turkey [28], and India [26]. It is also lower than Ghana [17], Ethiopia [25], Brazil [27], and India [26]. It is also lower than Greece [27], Malaysia [30], and Nigeria [12] as shown in Table 2.

The activity concentration of 232Th in this study is higher than World mean value [15], Spain [18], Cyprus [31], Qatar [19], Nigeria [16], Turkey [28], Ethiopia [24], Ghana [17], Turkey [29], Ethiopia [25], Iraq [22] and India [26]. It is also lower than [27], Malaysia [30], and Nigeria [12] as shown in Table 2.

The activity concentration of 40K in this study is higher than Qatar [19], Nigeria [16], Turkey [28], Ethiopia [25], Iraq [22] and It is also lower than Brazil [27], Malaysia [30], Ghana [17], India [26], Ethiopia [24], Nigeria [12], Turkey [29], Spain [(18), and Cyprus [31] as shown in Table 2. Variation in the radioactivity concentrations in soil/rock of various locations worldwide depends on the geographical and geological conditions of the region.

Table 1 & 3 shows the obtained radiological effects such as the radium equivalent (Raeq), the absorbed dose rate (D), the external (Hex) and the internal (Hin) hazard index, the radioactivity level index (Iy) and the annual effective dose equivalent(AEDE) and excess lifetime cancer risk(ELCR) for the gemstone rock/soil samples.

The Raeq for the gemstones of rock/soil samples was between 65.26 ± 8.36. Bq kg⁻¹ and 262.44 ± 34.36 Bq kg⁻¹ with an average value of 151.68 ± 19.46 Bq kg⁻¹. It is inferred that for all the soil samples analyzed, the radium equivalent activity value is well within and less than the permissible limits of 370 Bq kg⁻¹ [Beretka & Mathew, 1985]. The obtained absorbed dose rate varied from 30.08 ± 3.66 to 128.64 ± 14.89 nGy h⁻¹, with an average value of 72.19 ± 8.48 nGy h⁻¹. Some values are higher than the international recommended value 57 nGy h⁻¹ [32].

The calculated external hazard indexes (Hex) were varied from 0.18 to 0.78, with an average value of 0.43 and internal hazard indexes (Hin) 0.21 to 0.95 within the average value of 0.51. The calculated Iy values for all the samples are presented in Table 3. The values
ranged from 0.24 ± 0.03 to 1.02 ± 0.12 with an average of 0.57 ± 0.08.

The calculated outdoor AEDE values are quoted in Table 1. The results of outdoor effective dose from range of 0.04 ± 0.01 to 0.16 ± 0.01 mSv y⁻¹ within an average value of 0.07 ± 0.01 mSv y⁻¹.

5 Conclusion

In this research work, gamma radiation from gemstone soil/rock samples collected in the Delanta-dawunt was analyzed. Gamma-ray spectrometry was exploited to determine the activity concentration of natural radioactive isotopes that originated in the decay series of \(^{232}\)Th, \(^{226}\)Ra, together \(^{40}\)K were determined. The measured mean value of \(^{226}\)Ra is below the world average value, but for \(^{232}\)Th is higher than the world average value. The activities of concentration \(^{40}\)K are the same as the world average value. The mean annual effective dose equivalent is the same as the world recommended values. These results point out that the radiation hazard due to NORM radionuclides found in gemstone soil/rock samples from the sites studied in this work is not significant. Higher values of \(^{226}\)Ra, \(^{232}\)Th concentration, and radiation hazard levels were for the ABBS sample code and the lower value is in the sample code of KOK. The average value of absorbed dose rate is higher the world average value and other published paper that is compared with our results in Table 2.

6 Decelaration

Ethics approval and consent to participate

Not applicable

Competing Interests

The authors declare that they have no competing interests

Consent for publication

Not applicable

Author contribution

M.L, performed the analytic calculations and performed the data analysis and interpretations. Both Mekuanint Lemlem and A.K C authors contributed to the final version of the manuscript. A.K.C supervised the project.

Availability of data and materials

Additional data are available in the supplementary information file and upon request to the corresponding author.

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