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RESEARCH ARTICLE

EVALUATION OF RADIATION HAZARDS RESULTING FROM NATURAL RADIOACTIVITY ACTIVITIES AROUND AL-WAHDA CEMENT FACTORY IN ABYAN GOVERNORATE, YEMEN

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Abstract

The primary objective of this study is to measure the level of radioactivity in the soil around Al-Wahda Cement Factory in Abyan Governorate, Yemen, and to evaluate the radiological hazards of radionuclides. Twenty soil samples were collected from various locations in the Abyan Governorate (Izl Bates, Al-Hosn, Al-Rawa, Helmeh) to determine the activity concentrations of background radionuclides such as (Radium-226, Thorium-232, and Potassium-40). The activity concentrations were measured using gamma-ray spectrometry with a high-purity germanium detector (HPGe). The results show the activity concentration of ^{226}Ra ranged from 15.5 to 27.40 with an average value of 21.92Bqkg^{-1}. The activity concentrations of ^{232}Th ranged from 18.80 to 55.40 with an average value of 33.60Bqkg^{-1}. Activity concentrations of ^{40}K ranged from 248.70 to 660.40 with an average value of 572.40Bqkg^{-1}. The values of the average activity concentrations for ^{226}Ra and ^{232}Th are 21.92Bqkg^{-1} and 32.1Bqkg^{-1}, respectively, these values agree with these radionuclides present in soil worldwide (1.3-52.8) Bqkg^{-1} and (0.9-90.3) Bqkg^{-1} have been reported by UNSCEAR, 2008, respectively. The average activity of ^{40}K concentrations in soil is 572.4Bqkg^{-1} it is higher than the world average (412Bqkg^{-1}) reported by UNSCEAR 2008.Radiological hazard indices were evaluated based on radionuclide activity concentrations. The absorbed dose rates ranged from 34.38 to 66.82 nGy/h, with annual effective doses remaining below internationally recommended limits, indicating no significant radiological risk to cement factory workers or the surrounding environment.

Keywords: Soil samples; Specific activity; Absorbed dose; Abyan governorate; Cancer risk.

INTRODUCTION

Since the formation of the Earth, humanity has been exposed to both natural and artificial sources of radiation. Natural radiation includes cosmic radiation, external radiation from radionuclides in the Earth's crust, and internal radiation from radionuclides inhaled or ingested and retained within the body [1]. Radioactivity is the emission of radiation from the disintegration of unstable nuclei, releasing α or β particles or γ rays [3]. According to UNSCEAR, most human exposure to radiation originates from natural background radiation. Gamma radiation emitted from Naturally Occurring Radioactive Materials (NORMs), such as ^{238}U, ^{232}Th, and ^{40}K, constitutes the main source of external exposure to humans. The levels of these radionuclides in soil depend largely on the geological and geographical characteristics of the area [1, 4, 5]. Assessing radionuclide concentrations in soil provides valuable information on background radiation exposure and its potential effects on human health, as a significant proportion of terrestrial gamma radiation originates from the upper 0–25 cm layer of soil [6, 7]. In addition, medical applications, nuclear accidents, and other human activities contribute to artificial radiation exposure [2]. Numerous studies have been conducted to evaluate natural and artificial radioactivity in soil.

Several studies have assessed natural radioactivity levels and radiological hazards in soils and sediments from different regions, particularly in areas affected by industrial activities such as cement production [5, 13–16]. However, limited information is available regarding such assessments in Yemen. Therefore, this study aims to determine the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected around Al-Wahda Cement Factory in Abyan Governorate and to evaluate the associated radiological hazards. Furthermore, [16] assessed the levels of natural radioactivity and radiation hazards in soils from Erbil Governorate, Iraq, Kurdistan

[16]. The aim of this study is to determine the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples from the environment surrounding the Al-Wahda Cement Factory in Abyan Governorate, Yemen.

The results showed that the activity concentrations of ^{226}Ra and ^{232}Th were within the worldwide permissible ranges, whereas ^{40}K exhibited higher values than the global average, reflecting its natural abundance in the Earth's crust. Despite these variations, all calculated radiological hazard indices (Ra_{eq}, Dγ, AEDE, ELCR, Hex, Hin, AGDE, and H*(10)) were within internationally recommended limits, indicating that the studied area does not pose a significant radiological risk to workers, residents, or the surrounding environment. Consequently, this study provides important baseline data that can be used for future environmental monitoring and radiological assessment in the region.

2. MATERIALS AND METHODS

2.1. Description of Study Area:

This study focused on assessing the radioactivity levels in the soil surrounding Al-Wahda Cement Factory in Abyan Governorate, Yemen. This facility is one of the largest cement factories in the country and is situated approximately 20 km north of Zinjibar, the capital of Abyan Governorate. The site is located at the coordinates 45°17'37" N and 45°17'37" E, as illustrated in Figure 1.

2.2. Collection and Preparation of the samples:

Soil samples were collected with the stipulation that the sampling locations be positioned away from the boundaries of the Al-Wahda Cement Factory, ensuring isolation from adjacent areas such as Al-Hosn, Helmet, and Al-Rawaa. Topsoil was gathered from various spots within the designated area, specifically from the surface layer up to a depth of 2 cm, and these samples were thoroughly mixed to create a representative composite sample for the region. Each sample was dried in sunlight for several days and then sifted through an 18-mesh. sieve (equivalent to 1 mm), which is ideal for concentrating heavy metals. The processed samples were placed in plastic containers measuring 75 mm in diameter and 90 mm in height. After weighing, the samples were stored for a minimum of one month to allow the daughter products to reach radioactive secular equilibrium with their parent isotopes, ^{226}Ra and ^{232}Th. Counting of the samples was conducted for periods ranging from 8 to 24 hours, depending on the concentration of the radionuclides.

2.3. γ-Spectroscopy Analysis:

All samples were analyzed at the Nuclear Physics Laboratory of the Atomic Energy Organization in Sana'a, Yemen, using a gamma-ray spectrometer. The low-level background gamma-ray spectrometer utilized an HPGe detector, which was coaxial in design with a relative efficiency of 35% compared to a NaI (Tl) detector. The detector featured an active volume of 180 cm³ and was equipped with a beryllium end window. This closed-end coaxial gamma-ray detector (p-type) made of high-purity germanium (HPGe) operated in a vertical orientation and was cooled with liquid nitrogen. It had specifications including a resolution (FWHM) of ≤ 2.000 keV and ≤ 0.925 keV at 1.33 MeV and 122 keV, respectively, with a relative efficiency of 35%. The crystal dimensions were 70.6 mm in diameter and 70 mm in length, as shown in Figure 2.

Fig. 1: Illustrates the areas under study.

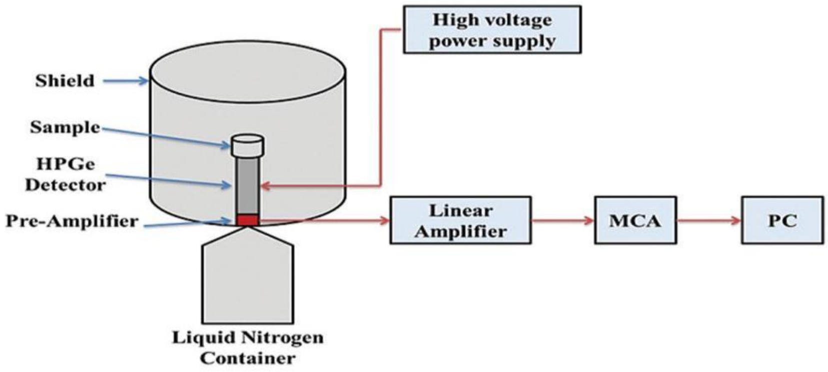

Fig. 2: Schematic layout of gamma-ray spectrometry system.

To minimize environmental background interference, the germanium crystal was housed within a lead shield. The detector was connected to a preamplifier, main amplifier, analog-to-digital converter (ADC), and multichannel analyzer. Energy calibration was performed using standard point sources (^{60}Co and ^{137}Cs), while efficiency calibration was conducted using standard QCYB41. Each sample was positioned in a face-to-face geometry with the detector for 10 to 24 hours to measure concentrations of ^{226}Ra, ^{232}Th, and ^{40}K. Background measurements were routinely taken each week under the same conditions as the sample measurements. The resulting spectra were analyzed using the Canberra Genie2000 software (Canberra Industries, Inc., USA) to calculate the levels of natural radioactivity.

2.4. Measuring activity of radionuclides:

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were determined using the following equation [17].

$$A_{Ei} = \frac{NP}{tc \, .I_{\gamma}\,(E_{\gamma}).\varepsilon(E_{\gamma}).M} \quad (1)$$

Where: NP is the number of counts in a given peak area corrected for background peaks of a peak at energy Eγ. tc is the counting lifetime. Iγ (Eγ) the number of gammas per disintegration of this nuclide for a transition at energy Eγ. ε (Eγ) the detection efficiency at energy Eγ and M the mass in kg of the measured sample. while tct_ctc is the counting lifetime. The term Iγ(Eγ) I_\gamma(E_\gamma) Iγ(Eγ) indicates the number of gamma emissions per disintegration of the nuclide for a transition at energy E and M represents the mass of the measured sample in kilograms.

The concentration of ^{226}Ra was calculated as the average of the activity detected at gamma-ray energies of 295.22 keV and 351.93 keV from ^{214}Pb, along with energies of 609.31 keV, 1120.29 keV, and 1764.49 keV from ^{214}Bi. Similarly, the concentration of ^{232}Th was determined using the average of the activities found at gamma-ray energies of 238.36 keV from the decay of ^{212}Pb, as well as 583.19 keV and 2614.5 keV from ^{208}Tl. The gamma-ray line at 1460.8 keV was utilized to measure the activity level of ^{40}K directly.

2.5. Radiological Hazard Indices

2.5.1. Radium Equivalent Activity (Ra_{eq})

The presence of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples is commonly used to estimate their overall radioactivity. The Radium Equivalent Index (Ra_{eq}) describes the total radiation exposure from these radionuclides and is expressed in Bq/kg. It is calculated using the following equation [17]

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

Where: A_{Ra}, A_{Th} and A_K is the activity concentration of ^{226}Ra, ^{232} Th and ^{40}K respectively, in Bq kg^{-1}.

2.5.2. Absorbed Gamma Dose Rate (Dγ)

The absorbed gamma dose rate in the air at a height of 1 meter above ground level can be calculated from the specific activities of natural radionuclides (^{226}Ra, ^{232}Th, and 40K) [4, 18]:

$$D\gamma\ (nGy/h) = 0.462A_{Ra}+0.604A_{Th}+0.0417A_{K} \quad (3)$$

D_\gamma \ (nGy/h) = 0.462 A_{Ra} + 0.604 A_{Th} + 0.0417 A_{K}D (4)

$$(nGy/h) = 0.462A_{Ra} +0.604A_{Th} +0.0417A_{K} \quad (5)$$

2.5.3. Annual Effective Dose Equivalent (AEDE)

The AEDE is derived from the absorbed gamma dose rate, measured in µSv/y, to assess potential health effects from DγD_\gammaDγ. The conversion factor of 0.7 Sv/Gy is used alongside the indoor occupancy factor (0.8) and the outdoor occupancy factor (0.2) to calculate the annual effective dose using these equations [2, 19]

$$\text{Outdoors: Dout nGy } h^{-1} \times 8760\ h \times 0.7\ Sv\ Gy^{-1} \times 0.2 \quad (6)$$

$$\text{Indoors: Din nGy } h^{-1} \times 8760\ h \times 0.7\ Sv\ Gy^{-1} \times 0.8 \quad (7)$$

2.5.4. Annual Gonadal Dose Equivalent (AGDE)

The gonads are highly sensitive to radiation exposure. The AGDE is calculated based on the specific activities of natural radionuclides in soil samples using the following equation [19]

$$AGDE = (3.09 \times A_{Ra} + 4.18 \times A_{Th} + 0.314 \text{ x } A_{K}) \times 10\text{-}3 \quad (9)$$

2.5.5. Excess Lifetime Cancer Risk (ELCR)

ELCR quantifies the additional cancer risk resulting from exposure to ionizing radiation and is derived from AEDE using the equation [20, 21]:

$$ELCR = (AEDE) \times DL \times DF \quad (10)$$

Where (DL) is the mean of human time of life (70 year), (DF) is the lethal risk factor per Sievert (0.05 Sv^{-1}).

2.5.6. External and Internal Hazard Indices

The external hazard index (Hex) reflects exposure to natural radiation, while the internal hazard index (Hin) indicates exposure to radon and its decay products. Both indices are calculated using the following equations [22, 23].

$$H_{ex} = A_{Ra} \backslash 370 + A_{Th} \backslash 259 + A_K \backslash 4810 \leq 1 \quad (11)$$

$$H_{in} = A_{Ra} \backslash 185 + A_{Th} \backslash 259 + A_K \backslash 4810 \leq 1 \quad (12)$$

2.5.7 Gamma Radiation Level Index (I_γ)

The gamma radiation level index (Iγ) assesses the risk of gamma radiation from natural radionuclides in soil. It can be calculated as follows [24, 25]:

$$I_{\gamma r} = A_{Ra} \backslash 150 + A_{Th} \backslash 100 + A_K \backslash 1500 \leq 1 \quad (13)$$

2.5.8. Ambient Dose Equivalent Rate H(10)*

The ambient dose equivalent rate quantifies the effective dose and evaluates health risks associated with radiation exposure. It is calculated for ^{226}Ra, ^{232}Th, and ^{40}K in the air at a height of 1 meter above ground level using the following equation [2, 6]:

$$H^*(10)\ (nSv/h) = 0.674\ A_{Ra} + 0.749\ A_{Th} + 0.0512\ A_K \quad (14)$$

This formulation allows for a comprehensive assessment of the radiological impact of these radionuclides.

3. RESULTS AND DISCUSSION

3.1. Activity Concentrations of the Radionuclides

The specific activity concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in soil samples from the Al-Wahda Cement Factory are summarized in Table I and illustrated in Figure 3 below. The concentration of ^{226}Ra varies from (15.5 ± 0.48) Bq/kg in sample (1) from the Al-Rawa region to (27.4 ± 0.85) Bq/kg in sample (16) from the Isl-Battis region, resulting in a mean value of (21.92 ± 0.68) Bq/kg.

For ^{232}Th, the specific activity ranges between (18.8 ± 0.50) Bq/kg in sample (16) from Isl-Battis to (55.4 ± 1.48) Bq/kg in sample (8) from the Al-Hosn region, yielding an average of (33.6 ± 0.89) Bq/kg. The obtained results indicate spatial variations in the activity concentrations of natural radionuclides among the collected soil samples. These variations are primarily attributed to differences in geological formations, mineral composition, parent rock characteristics, weathering processes, and other environmental factors that influence the distribution of naturally occurring radionuclides.

The average activity concentration was lower than or close to the corresponding worldwide average values, indicating that the natural radioactivity levels in the study area are within the normal background range. The relatively higher values observed in some samples are most likely associated with local geological and mineralogical characteristics rather than anthropogenic radioactive contamination.

Overall, the measured activity concentrations suggest that the study area exhibits normal natural radioactivity levels and does not pose any significant radiological risk to human health or the surrounding environment [32].

The specific activity of 40K shows a range from (248.7 ± 4.15) Bq/kg in sample (16) from Isl-Battis to (660.40 ± 11.02) Bq/kg in sample (8) from Al-Hosn, with a mean value of (572.4 ± 9.55) Bq/kg.

The mean activity concentrations of (^{226}Ra, ^{232}Th, and ^{40}K) are lower than the worldwide average values recommended by UNSCEAR (2000), which are 33 Bq/kg, 30 Bq/kg, and 400 Bq/kg, respectively. This indicates that the studied area is generally within normal background radiation levels. However, the relatively higher values of ^{40}K reflect its natural abundance in soil and its strong geochemical association with clay minerals. Table I.

Table I: Specific activity of (^{226}Ra, ^{232}Th, and ^{40}K) in the soil samples collected from al-Wahda cement factory.

			Activity concentration Bqkg-1		
Sample No.	Area	Type of Soil	Ra-226	Th- 232	K-40
1	Al-Rawa	Clay	15.5±0.48	32.2±0.86	546.8±9.13
2	Al-Rawa	Clay	20.9±0.65	28.5±0.76	628.7±10.49
3	Al-Rawa	Clay	21.7±0.67	28.9±0.77	615±10.26
4	Al-Rawa	Clay	23.6±0.74	26.8±0.72	631.7±10.54
5	Al-Hosn	Clay	22.0±0.68	34.0±0.91	660.4±11.02
6	Al-Hosn	Sand	15.7±0.49	30.9±0.83	583.2±9.73
7	Al-Hosn	Sand	19.4±0.60	40.0±1.07	554.9±9.26
8	Al-Hosn	Sand	24.9±0.77	55.4±1.48	524.2±8.75
9	Al-Hosn	Sand	26.0±0.80	39.9±1.06	580.4±9.69
10	Al-Hosn	Clay	18.9±0.58	32.6±0.87	551.4±9.20
11	Isl Battis	Clay	24.0±0.74	32.6±0.87	607.6±10.14
12	Helmeh	Clay	21.3±0.66	33.5±0.89	633.5±10.57
13	Helmeh	Clay	15.6±0.48	27.8±0.74	623.4±10.40
14	Isl Battis	Clay	22.7±0.70	33.9±0.91	593.5±9.91
15	Isl Battis	Clay	23,5±0.73	36.7±0.98	546.2±9.12
16	Isl Battis	Cement	27.4±0.85	18.8±0.50	248.7±4.15
17	Isl Battis	Clay	21.9±0.68	33.3±0.89	561.5±9.37
18	Isl Battis	Clay	25.6 ±0.79	35.9±0.96	541.5±9.04
19	Isl Battis	Clay	21.8±0.67	31.9±0.85	609.5±10.17
20	Isl Battis	Clay	25.9±0.81	38.4±1.03	606.1±10.12
Mean			21.92±0.68	33.6±0.89	572.4±9.55

Fig. 3: Variations of specific activity of ^{226}Ra, ^{232}Th, and ^{40}K) in the soil samples

Table II presents a comparison of the average specific activity levels of radionuclides 226Ra, 232Th, and ^{40}K from this study with findings from other local and global research that are similar in nature. The average specific activity of ^{226}Ra in this study aligns closely with values reported in Turkey and the Rabia region of Nineveh Governorate. Meanwhile, the average concentration of ^{232}Th is comparable to findings from studies conducted in Egypt and South Korea [6]. Additionally, the specific activity of ^{40}K in this study is consistent with values observed in Egypt. This comparative analysis highlights the relevance of the findings within the broader context of regional and international studies.

Table II: A comparison of the average specific activity in (Bq/kq) of (^{226}Ra, ^{232}Th, and ^{40}K in this study with similar study in another local and global region.

Country	Activity concentration Bq kg^{-1}			Reference
	Ra-226	Th - 232	K-40	
al-wahda cement, factory Yemen	21.92±0.68	33.6±0.89	572.4±9.55	Present work
South Korea	21.92±0.68	33.6±0.89	572.4±9.55	Lee et al., 2023 [6]
Turkey	48.2±4.4	41.7±4.5	939.1±36	Turhan, 2023 [26]
Turkey	44.4±4.5	58.2±5.1	822.7±31	Isel et al., 2023 [5]
Iran	80.77±10	211.5±14	1004±40	Shahroudi and Pouriman, 2023 [13]
Iraq	3.95	2.53	260.36	Raghad et al., 2018 [27]
Iraq, Kirkuk	16.7±2.7	19.4±5	262±82	Taqi and Nomp, 2022 [11]
Iraq, Duhok	22-104	21-103	138-601	Abdullah and Ahmed, 2012 [28]
Saudi Arabia	32.9 ± 6.65	28.2 ± 0.78	193.8 ± 1.55	Mansour et al., 2020 [29]
Iraq, Kurdistan	14.5±3.9	11.2±3.9	225±63	Smail et al., 2021 [14]
Iraq, Hamam AL-Alil	11.17	13.38	158.36	Ali and Laith, 2023 [2]
Turkey	24.5	38.4	621.4	Selim Kaya et al.,2020 [30]
Serbia	4.75 ± 0.2	6.5	100.7	Milena et al., 2023 [31]
Worldwide Ave.	**33**	**30**	**400**	**UNSCEAR, 2008**

3.2. Radiological Hazard Indices

The radiological hazard indices have been calculated based on the activity concentrations of radionuclides in the studied area. Table III summarizes the radiological hazard indices for soil samples collected from the Al-Wahda Cement Factory. The radium equivalent activity (Ra_{eq}) values range from (73.43 Bq/kg) to (144.48 Bq/kg), with an average of (114.04 Bq/kg). All Raeq values are below the permissible limit of 370 Bq/kg as recommended by UNSCEAR (2000).

The absorbed dose rate (Dγ) varies between (34.38 nGy/h) and (66.82 nGy/h), with a mean value of (66.58 nGy/h). Notably, all Dγ values are below the global average of 55 nGy/h (UNSCEAR, 2000). The indoor equivalent annual effective dose (AEDEin) and outdoor equivalent annual effective dose (AEDEout) were also calculated. The AEDEin ranges from (168.65 µSv/y to 327.79 µSv/y), with a mean of (266.31 µSv/y). In contrast, AEDEout varies between (42.17 µSv/y and 81.95 µSv/y), averaging (66.60 µSv/y). Both AEDEin and AEDEout fall within the global average limit of 1000 µSv/y (UNSCEAR, 2000).

The excess lifetime cancer risk (ELCR) values range from (147.595 × 10^{-6} to 286.825 × 10^{-6}), with an average of (233.019 × 10^{-6}), which is lower than the global average of 290 × 10^{-6} (UNSCEAR, 2000). For the external (Hex) and internal (Hin) radiological indices, Hex values range from (0.198 to 0.390), with a mean of (0.308). Meanwhile, Hin ranges from (0.272 to 0.457), averaging (0.367). The gamma radiation level index (Iγ) for all samples falls between (0.55 and 1.07), with an average of (0.864). All values for Hin, Hex, and Iγ are below one, which is the recommended threshold by UNSCEAR (2000), indicating that the samples adhere to safety standards.

The annual gonadal dose equivalent (AGDE) ranges from (241.34 to 473.11) µSv/y, with a mean value of (387.90 µSv/y). These AGDE values exceed the global permissible limit of 300 µSv/y (UNSCEAR, 2000). Lastly, the ambient dose equivalent rate (H*(10)) varies from (46.13 nSv/h to 92.69 nSv/h), with an average of (72.56 nSv/h).

Table III: Radiological Hazard Indices for ^{226}Ra, ^{232}Th, ^{40}K radionuclides in al-wahda cement factory.

Sample No.	Location	Ra_{eq} (Bqkg^{-1})	$I_{\gamma r}$	H_{ex}	H_{in}
1	Al-Rawa	103.56	0.79	0.279	0.322
2	Al-Rawa	110.06	0.84	0.297	0.354
3	Al-Rawa	110.38	0.84	0.298	0.357
4	Al-Rawa	110.56	0.85	0.298	0.362
5	Al-Hosn	121.47	0.93	0.328	0.387
6	Al-Hosn	104.79	0.80	0.283	0.325
7	Al-Hosn	119.33	0.90	0.322	0.375
8	Al-Hosn	144.48	1.07	0.390	0.457
9	Al-Hosn	127.75	0.96	0.345	0.415
10	Al-Hosn	107.97	0.82	0.291	0.343
11	Isl Battis	117.40	0.89	0.317	0.382
12	Helmeh	117.98	0.90	0.319	0.376
13	Helmeh	103.35	0.79	0.279	0.321
14	Isl Battis	116.88	0.88	0.316	0.377
15	Isl Battis	118.04	0.89	0.319	0.382
16	Isl Battis	73.43	0.55	0.198	0.272
17	Isl Battis	112.75	0.85	0.304	0.364
18	Isl Battis	118.63	0.89	0.320	0.389
19	Isl Battis	114.35	0.87	0.309	0.368
20	Isl Battis	127.48	0.961	0.344	0.414
Mean		**114.04**	**0.864**	**0.308**	**0.367**

5. CONCLUSION

The results of the study conducted in the vicinity of Al-Wahda Factory in Abyan Governorate, Yemen, reveal concentrations of natural radioactivity in the surface soil, including the natural isotopes ^{232}Th, ^{226}Ra, and ^{40}K. The radioactivity was measured using High Purity Germanium (HPGe) gamma-ray spectrometry at the National Atomic Energy Authority Laboratory in Sana'a.

In this study, 20 soil samples collected from the surroundings of Al-Wahda Cement Factory were analyzed to evaluate natural radioactivity levels. Gamma-ray spectrometry using a high-purity germanium

(HPGe) detector was employed to determine the activity concentrations of naturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K). The calculated radiological hazard indices indicated that ^{40}K contributed the highest activity concentration among the measured radionuclides, reflecting its natural abundance in the Earth's crust. Variations in radionuclide concentrations among the soil samples may be attributed to differences in the physical, chemical, and geological characteristics of the study area. The activity concentrations of ^{226}Ra and ^{232}Th were found to be within the worldwide average values, whereas the average concentration of ^{40}K exceeded the global average. The values of all radiological hazard indices, including Ra_{eq}, Dγ, AEDE, ELCR, Hex, Hin, AGDE, and H*(10), were below the internationally recommended limits. Therefore, the results indicate that there are no significant radiological hazards associated with continuous exposure to ionizing radiation from naturally occurring radionuclides for workers at the cement factory or for organisms inhabiting the surrounding environment. This study provides important baseline data on natural radioactivity and radiological hazards in the investigated area.

Recommendations

1. **Periodic radiological monitoring** of soil, dust, and raw materials in and around Al-Wahda Cement Factory is recommended to establish a continuous database on natural radioactivity levels and to detect any future changes associated with industrial activities.
2. **Expanding the scope of future studies** to include other environmental matrices, such as groundwater, surface water, air particulates, vegetation, and building materials, is recommended to provide a comprehensive radiological assessment of the area.
3. Further investigations involving **seasonal sampling and a larger number of sampling locations** should be conducted to improve the spatial and temporal representation of radionuclide distribution in the study area.
4. The use of **geographical information systems (GIS) and radiological mapping techniques** is recommended to identify potential hotspots and support environmental management and decision-making processes.
5. Although the radiological hazard indices obtained in this study were within internationally recommended limits, **occupational and environmental radiation protection measures should continue to be maintained** to ensure the long-term safety of workers and nearby communities.
6. The findings of this study may serve as **baseline reference data** for future environmental radioactivity assessments and for the development of national guidelines related to radiological monitoring in Yemen.

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مقالة بحثية

تقييم المخاطر الاشعاعية الناتجة عن أنشطة النشاط الطبيعي حول مصنع الإسمنت في محافظة أبين، اليمن

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المُلخّص

تتمثل الأهداف الرئيسية لهذه الدراسة في قياس مستوى النشاط الإشعاعي في التربة المحيطة بمصنع إسمنت الوحدة في محافظة أبين، اليمن، وتقييم المخاطر الإشعاعية للنظائر المشعة. تم جمع عشرين عينة تربة من مواقع مختلفة في محافظة أبين، شملت عزلة باتيس، الحصن، الرواء، وحلمة، وذلك لتحديد تركيزات النشاط الإشعاعي للنظائر المشعة الطبيعية، وهي الراديوم-226 (^{226}Ra)، والثوريوم-232 (^{232}Th)، والبوتاسيوم-40 (^{40}K). وقد قِيست تركيزات النشاط الإشعاعي باستخدام مطيافية أشعة غاما بواسطة كاشف الجرمانيوم عالي النقاء (HPGe). أظهرت النتائج أن تركيز النشاط الإشعاعي للراديوم-226 تراوح بين 15.5 و27.40 بيكريل/كجم، بمتوسط بلغ 21.92 بيكريل/كجم. كما تراوحت تركيزات الثوريوم-232 بين 18.80 و55.40 بيكريل/كجم، بمتوسط قدره 33.60 بيكريل/كجم. أما البوتاسيوم-40 فقد تراوحت تركيزاته بين 248.70 و660.40 بيكريل/كجم، بمتوسط بلغ 572.40 بيكريل/كجم. وأظهرت النتائج أن متوسط النشاط النوعي لهذه النظائر المشعة كان أقل من المعدل العالمي بالنسبة للراديوم-226، وضمن المعدل العالمي للثوريوم-232، بينما تجاوز المعدل العالمي بالنسبة للبوتاسيوم-40. كما جرى تقييم مؤشرات المخاطر الإشعاعية استنادًا قسم إلى تركيزات النشاط الإشعاعي للنظائر المشعة في منطقة الدراسة. وتراوحت قيم الجرعة الممتصة ($D\gamma$) بين 34.38 و66.82 نانوغري/ساعة، بمتوسط بلغ 66.58 نانوغري/ساعة. وأوضحت النتائج أن قيم الجرعات الممتصة والجرعات الفعالة السنوية المحسوبة جاءت أقل من مستويات السلامة الموصى بها دوليًا، مما يشير إلى عدم وجود مخاطر إشعاعية كبيرة على العاملين في مصنع الإسمنت أو على الكائنات الحية المحلية. وقد تمت مناقشة نتائج الدراسة ومقارنتها بنتائج دراسات مماثلة وبالقيم الموصى بها عالميًا.

الكلمات المفتاحية: عينات التربة؛ النشاط النوعي؛ الجرعة الممتصة؛ محافظة أبين؛ خطر الإصابة بالسرطان.

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