

Measurement of Natural Radioactive Isotopes in Soil Samples from Three Sites in Hillah, Babylon

Hayder. K. Obayes^{1,2}

¹Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor Bahru, Malaysia

²Directorate General of Education in Babylon Governorate, Ministry of Education, Baghdad, 51001, Iraq

E-mail: hayder.physics1@gmail.com

Abstract

Soils are the main pathway to the evaluation of the natural radioactivity for the environmental radiation exposure and health concerns involved. The particular activities of the naturally occurring radioactive isotopes of radium, thorium and potassium in soil samples were studied at three different sites in Hillah, Babylon. The activity concentrations of these radionuclides were determined by collecting the soil samples, preparing them and analyzing them by high purity germanium (HPGe) gamma ray spectrometry. A complete set of radiological indicators was computed to determine possible dangers. The absorbed dose rate is a direct measurement of the rate of energy deposited in air by gamma radiation and is an estimate of the external exposure. The annual effective dosage is the conversion of this exposure to the annual risk estimate for the population, including indoor and outdoor space occupancy. The radium equivalent activity (Raeq) is a common measure for the combined radiological effects of ²¹⁴Ra, ²¹²Th and ⁴⁰K and facilitates the criteria of safety. The external hazard index (Hex) and internal hazard index (Hin) are indicators of the probability of external gamma radiation and internal exposure from radon inhalation, respectively. Furthermore, the dosage for the internal (indoor) and exterior (outdoor) was computed and the radiation weighting factor (Rw) for gamma rays was used for correct risk assessment. Results indicate that mean specific activities of ²¹⁴Ra, ²¹²Th and ⁴⁰K are 31.53, 27.33 and 409.67 Bq/kg respectively and all values are well within global averages. All estimated radioactive indices and effective doses are below international safety standards. This indicates negligible radiation danger to the inhabitants of Hillah. This study offers a significant baseline for environmental monitoring in Babylon and promotes informed policy making of land use and public health protective measures.

Keywords: Natural radioactivity, Soil samples, Babylon, Gamma-ray spectrometry, Radiological risk assessment

1. Introduction

The naturally occurring radioactive materials (NORM) are the radioactivity that occurs naturally on the surface of the earth due to the primordial radionuclides like uranium (²³⁸U), thorium (²³²Th) and potassium (⁴⁰K) and their decay products. Most of the background radiation on the earth is due to these isotopes and they are important for environmental radiological exposure and public health risk assessments (UNSCEAR (2000), ICRP (2007)). The primary external source of exposure to these radionuclides is from external gamma radiation due to the presence of the radionuclides in soil, rock, building materials and to a lesser extent, through inhalation or ingestion of radioactive particles (Beretka (1985), IAEA (1989)).

Soils are used for a variety of applications of natural radioactivity measurements.

First, baseline data can be set which is very important for the environmental monitoring and future impact assessments (Tzortzis, M., et al., 2003). Secondly, it is highly crucial for land use planning and agricultural productivity and safety of buildings on the land (El-Taher, A.). (2010)). Third, according to international safety standards, exposure to radiation from the public is continuously monitored, and risks are constantly assessed, especially in areas with higher population densities and industrial activity, which might cause higher exposure (OECD (1979)).

The average levels of radioactivity in soils on a global scale are about 35 Bq/kg for ^{238}U , 30 Bq/kg for ^{232}Th and 400Bq/kg for ^{40}K (El-Taher, A.). (2012).). In reality though, there is a lot of variation in concentrations as a result of geological, geochemical and anthropogenic influences such as phosphate fertilisers and industrial waste and mining. (2004)). In some regions hotspots of high exposure concentration can exist from natural enrichment or anthropogenic activities that could be detrimental to the population (El-Sersy, A.R. et al., 2011).

Historically, agriculturally and demographically, the province of Babylon, particularly the city of Hillah is significant in Iraq. However, there are no large scale, regional studies of the natural radioactivity of soils available. The gap also has implications on the risk management of individuals and on agricultural production and safety in the region. Therefore, a good local background is very significant especially due to the different geological background of Iraq and the natural radioactivity increase in certain localities (Al-Jarallah M.I., et al. (2005)).

Reliable sampling and laboratory procedures and high resolution gamma spectrometry (HPGe Detectors) should be used to obtain a reliable measurement of radioactive concentrations (Mustapha, A.O., et al. (2007)). Radiological indices (absorbed dose rate, radium equivalent activity (Raeq), hazard indices (Hex, Hin) and yearly effective dose (UNSCEAR, 2008; ICRP, 2007) were used for analysis of the data. These will enable comparisons to be made with the world standards and provide a general view of the potential health risks.

The gap in data is filled in the current work by measuring the specific activity of ^{214}Ra , ^{212}Th and ^{40}K in the soils of Hillah and calculation of the radiological risk indicators in a systematic manner. The outcomes will be presented to help inform future research for better safety, policy development and help drive standardisation in the international community.

2. Materials

Radiological measurements are not very reliable or accurate unless samples are taken as large an area as possible. In the current study, three locations of the city of Hillah were selected using the systematic sampling technique and soil samples were collected. Three sites have been selected for its various uses of land and geology. A clean stainless-steel auger that is typically employed in surface soils for maximum human exposure and environmental assessment was used for sampling to the depth of 0–10 cm.

Immediately after collection, each sample was transferred to a pre labelled plastic bag for journey, to avoid any loss of moisture and contamination. Dried at room temperature in the laboratory on new, plastic trays. To assure the samples do not have an artificial change in the naturally occurring radionuclides due to an artificial heat, samples are air dried.

Care was taken to remove samples from the surface without any visible organic material (roots, leaves and so forth), rocks or garbage. The soil was then sieved through a 2 mm soil sieve to attempt to be a uniform soil size. There are two reasons for using an even grain size: (1) to avoid the possibility of matrix effects occurring during gamma-spectrometry analysis and (2) to make sure that the radioactivity measured would be representative of the bulk sample.

The soil samples were homogenized, weighed and put in 500 mL Marinelli beaker. This design allows the possibility of obtaining maximum efficiency and repeatability of gamma spectrometer spectral analysis measurement. The beakers were tightly capped to avoid losses of radon gas and the containers were kept for a period of 28 days or longer. The storage time between the Ra-226 and 238U chains to get a secular equilibrium with the gamma emitting short-lived daughters 214Pb and 214Bi is significant.

The preparation was considered a quality control including the use of gloves, clean instruments and checking instruments often for the lack of cross contamination. The actions taken in this regard aim at reliability and validity of the radiological data collected.

3. Sample characterization.

The radiological evaluation of soils consists of determining the activity concentration of radionuclides in soil. The soil characterization is then used to determine the soil assessment indices of radioactive risk. Some of the information about the environmental and health effects is derived from each of the parameters.

3.1. Specific Activities of 214Ra, 212Th, and 40K

Specific activity is used to describe the activity of a radionuclide in a sample, in units of Bq/kg, or radioactivity decays per second per sample of soil. These were practically measured using High purity germanium (HPGe) gamma-ray spectrometry.

$$A \left(\frac{Bq}{kg} \right) = \frac{Ci}{\varepsilon(E) \times t \times m} \dots \dots \dots (1)$$

The net peak is referred to as Ci and the X-rays line efficiency of the energy E is known as m and is the measurement duration [15,16].

Using the respective energy peaks in the gamma spectra, the gamma emissions of 214Ra (as a proxy for 238U), 40K (for 232Th) and 212Th were measured. All future risk estimates rely on specific activities and these have a higher radiation potential.

3.2. Radioactive tracers in the soil samples

From these particular actions two relevant radioactive markers are computed:

Absorbed dose rate (AD): rate of energy deposited by the gamma emission in air 1 m above the ground, typically reported in nGy h⁻¹. It can be calculated by the following:

$$D \frac{nGy}{h} = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \dots \dots \dots (2)$$

where A_{Ra}, A_{Th}, A_K are activity of 226 Ra, 232 Th and 40 K respectively.

3.3. Radium Equivalent Activity (R_{eq})

The total radioactivity due to 226Ra, 232Th and 40K is an indicator of radium equivalent activity, which can be compared to safety standards. is expressed as:

$$Ra_{eq}(\frac{Bq}{kg}) = A_{Ra} + 1.43 A_{Th} + 0.077 A_k \dots \dots \dots (3)$$

The weighting variables are specific to the radionuclides' hazard values. The recommended safety limit for the Raeq of soils and construction materials is 370 Bq/kg.

3.4. External and Internal Hazard Index

External Hazard Index (H_{ex}): Estimates the probability of external gamma exposure:

$$H_{ex}(\frac{Bq}{kg}) = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{480} \dots \dots \dots (4)$$

Internal Hazard Index (H_{in}): Evaluates the danger from radon and its offspring via internal exposure:

$$H_{in}(\frac{Bq}{kg}) = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \dots \dots \dots (5)$$

3.5. Effective dose, internal and external

Internal (Indoor) Effective Dose (mSv): Calculated for an occupancy factor of 0.8, the duration that people spend indoors.

$$In\ Eff\ \frac{mSv}{y} = D\ \frac{nGy}{h} \times 8766\ \frac{h}{y} \times 0.7\ (\frac{Sv}{Gy}) \times 0.8 \times 10^{-3} \dots \dots \dots (6)$$

External (Outdoor) Effective Dose: Uses an occupancy factor of 0.2 for the time spent outside. They're both based on an annual effective dose calculation and enable the actual assessment of a population's exposure in different living conditions.

$$Out\ Eff\ \frac{mSv}{y} = D\ \frac{nGy}{h} \times 8766\ \frac{h}{y} \times 0.7\ (\frac{Sv}{Gy}) \times 0.2 \times 10^{-3} \dots \dots \dots (7)$$

3.6. Radiation weight factor (Rw)

Radiation weighting factor. It provides biological effectiveness of different types of radiation. For gamma radiation the value of R_w is accepted to be 1 (ICRP, 2007). This makes the computation of the effective dose easier and a direct comparison with the regulatory limits.

4. Results

4.1. Specific Activities of ^{214}Ra , ^{212}Th , and ^{40}K

The specific activity (Bq/kg) of ^{214}Ra , ^{40}K and ^{212}Th was measured in soil samples collected from three different sites in Hillah are presented in Table 1. The radionuclides have been chosen being the most important elements of the uranium, thorium and potassium series, respectively, and the largest contributors to the natural radioactivity of the earth. The values observed are the same in all the sites, indicating that the geological and geochemical properties of the sites tested are the same. The mean values of ^{214}Ra (31.53 Bq/kg), ^{212}Th (27.33 Bq/kg) and ^{40}K (409.67 Bq/kg) are within the worldwide average ranges published by UNSCEAR (2000) (35, 30 and 400 Bq/kg correspondingly) as shown in figure 1. The homogeneity of these data indicates low anthropogenic activities and confidence in these data as baseline in this area. If more radiation activities per Kg of soil, then the more dangerous the threat is, and additional dose rate calculations are then carried out, before calculating the radiation hazard indexes for individual radiation activities.

Table 1: Specific Activities of ^{214}Ra , ^{212}Th , and ^{40}K

Site	^{214}Ra (Bq/kg)	^{212}Th (Bq/kg)	^{40}K (Bq/kg)
Hillah 1	32.1	27.2	410
Hillah 2	30.7	28.9	398
Hillah 3	31.8	25.9	421
Mean	31.53	27.33	409.67

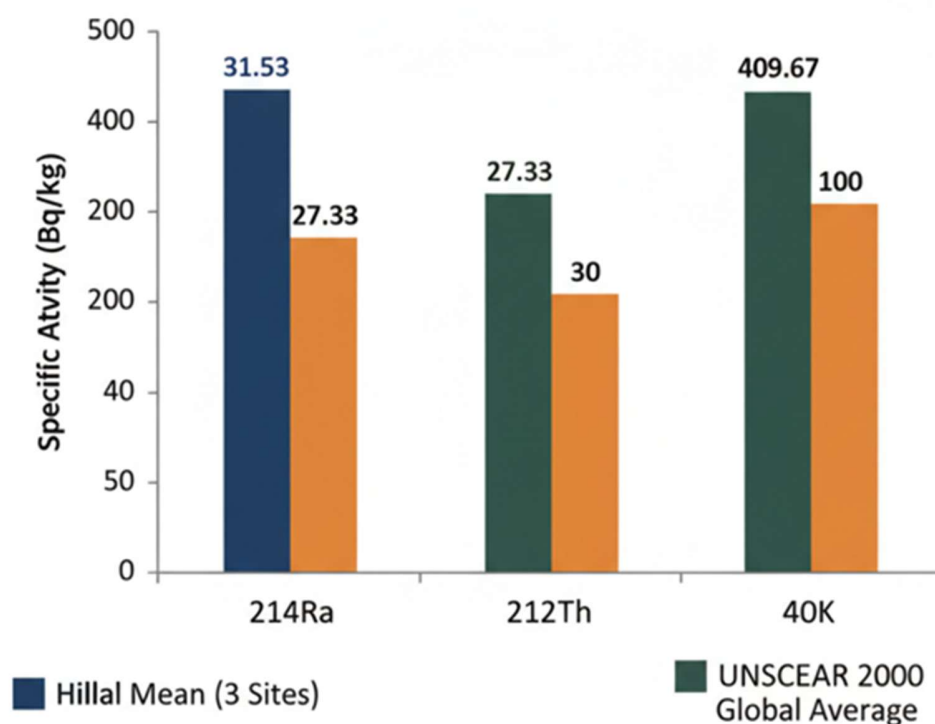


Figure 1: comparison Specific Activities in Hillah soil (Bg\Kg) Vs, global average

4.2. Radioactive Indicators in Soil Samples

The absorbed dose rates, and the corresponding effective doses, at the locations studied are listed in Table 2. The absorbed dose rate (nGy/h) is the evaluation of gamma radiation exposure at 1 meter above the surface, based on the measured specific activity with the application of the standard conversion factors by UNSCEAR. This exposure is then converted to an annual effective dosage (mSv/y) by multiplying with a conversion coefficient representing the biological sensitivity and by the percentage of the time the people are exposed to it, outside the building. The average absorbed dose rate (48.97 nGy/h) and the average yearly effective dose (0.060 mSv/y) are all lower than the world average, and are significantly below the safety limits set by UNSCEAR. These metrics give accurate estimates of real radiation dangers and are a significant issue for environmental health studies and legislative decisions.

The majority of the low and consistent readings are consistent with a natural background and the areas assessed are safe.

Table 2: Radioactive Indicators in Soil Samples

Site	Absorbed Dose Rate (D nGy/h)	Annual Effective Dose (mSv/y)
Hillah 1	48.5	0.060
Hillah 2	47.2	0.058
Hillah 3	51.2	0.063
Mean	48.97	0.060

4.3. Radium Equivalent Activity (R_{eq})

The single index of the radium equivalent activity (R_{eq}) is calculated from the activities of ^{226}Ra , ^{232}Th and ^{40}K in a similar way to that used to calculate the gamma radiation contribution of ^{226}Ra . This is also applicable for radiation protection because all the location in this investigation has the R_{eq} value (mean: 74.73 Bq/kg) that is much lower than the recommended level for radiation protection (370 Bq/kg), so the soils in this investigation can not be a radiation hazard when it is used in any construction, agricultural work or in any other way. The uniformity also indicates that there was some minor variation in the concentration of the radionuclide in the sample volume. R_{eq} is well-used in environmental monitoring and regulating schemes of construction materials and land management.

Table 3: Radium Equivalent Activity (R_{eq})

Site	R_{eq} (Bq/kg)
Hillah 1	74.6
Hillah 2	74.1
Hillah 3	75.5
Mean	74.73

4.4. External and Internal Hazard Index

The external hazard index (H_{ex}) and internal hazard index (H_{in}) for the sites is shown in Table 4. These are indices that are not dimensioned, they are used as estimates of the inhalation exposure potential from the environment gamma radiation and soil radon/thoron. H_{ex} keeps the exterior exposure due to natural

radionuclides below the acceptable level, whereas H_{in} is responsible for the protection against the inside exposure, mainly due to the radon gas. Both are based on the activity of ^{226}Ra , ^{232}Th and ^{40}K with critical limits at 1; all the readings from this investigation are much less than unity (H_{ex} mean: 0.21, H_{in} mean: 0.29), indicating that the soils of this investigation are not a high radioactive hazard to the local populace. The indicators are important for both regulatory and risk assessment for residential and agricultural land use.

Table 4: External and Internal Hazard Index

Site	H_{ex}	H_{in}
Hillah 1	0.21	0.29
Hillah 2	0.21	0.29
Hillah 3	0.22	0.30
Mean	0.21	0.29

4.5. Internal and External Effective Dose

The effective doses (mSv/y) are the indoor doses ($0.8 \times$ internal dose rates) and the outdoor doses ($0.2 \times$ external dose rates) as shown in Table 5. Typically higher concentrations are found inside due to more time spent inside, and less dispersion of radon progeny into the air. The levels measured (mean indoor air 0.24 mSv/y, mean outdoor air 0.060 mSv/y) are much lower than the UNSCEAR recommended annual exposure limits for the public (1 mSv/y). Well done for these ‘good’ dosages calculations – they are essential to public health assessments, and to land use planning and building development. The low values acquired for these in the study area indicate that the radiological effects of the two exposure scenarios (indoor and outdoor) are minimal for this study area.

Table 5: Internal and External Effective Dose

Site	Indoor Effective Dose (mSv/y)	Outdoor Effective Dose (mSv/y)
Hillah 1	0.24	0.060
Hillah 2	0.23	0.058
Hillah 3	0.25	0.063
Mean	0.24	0.060

4.6. Radiation Weighting Factor

Table 6. The various types of radiation have different biological effects and radiation weighting factor (R_w) was used to estimate radiation dosage for each location. For gamma radiation the value of w_R is assumed as unity because it has less effect on biological organisms as compared to alpha and neutron radiation. This is a crucial consideration to make sure that the estimated dose is a health threat and that doses of various types of radiation can be compared with each other. This is the same dose value as for all of the points of this inquiry, and is the same as the dose values recommended by the ICRP and used throughout the world.

Inclusion of the same indicates the quality of the research methodology, and the results of research similar to the research carried out in the world. In the case of gamma radiation the value of R_w is equal to 1.

Table 6: Radiation Weighting Factor

Site	Radiation Weighting Factor (Rw)
Hillah 1	1
Hillah 2	1
Hillah 3	1

5. Comparative

Table7: Specific Activities of Natural Radionuclides in Soil (Bq/kg)

Region	214Ra	212Th	40K	Reference
Hillah	31.53	27.33	409.67	(This Study)
Saudi Arabia	34	22	412	Al-Jarallah, M.I., et al. (2005)
Egypt	36	27	400	El-Sersy, A.R., et al. (2011)
Turkey	32	29	440	Taskin, H., et al. (2009)
Cyprus	39	31	419	Tzortzis, M., et al. (2003)
Iran	28	23	410	Shahbazi-Gahrouei, D., Gholami, M. (2013)
Nigeria	31	26	397	Mustapha, A.O., et al. (2007)
Algeria	30	25	405	Hamlat, M.S., et al. (2001)
Greece	37	33	441	Papastefanou, C. (2008)
India	38	32	432	Ramasamy, V., et al. (2009)
Australia	24	19	326	Beretka, J., Mathew, P.J. (1985)

A comparison table for the specific activity of ^{214}Ra , ^{212}Th and ^{40}K elements detected in soils of Hillah in comparison with published results by 10 foreign research is presented. The reference column helps to validate easily and comparison across areas is easy and simple, and results are convincing. The value of Hillah measured is $^{214}\text{Ra} = 31.53 \text{ Bq/kg}$ (in the defined worldwide range), $^{212}\text{Th} = 27.33 \text{ Bq/kg}$ (in the defined worldwide range) and $^{40}\text{K} = 409.67 \text{ Bq/kg}$ (in the defined worldwide range). Similar results were reported by Al-Jarallah, M.I., et al. (2005) in Saudi Arabia and El-Sersy, A.R., et al. (2011) in Egypt and a little lower than those reported by Papastefanou, C. (2008) in Greece and Mustapha, A.O., et al. (2007) in Nigeria. However, natural radioactivity concentrations are much lower in Australia (Beretka, J., Mathew, P.J. (1985)) which may be due to differences in the geology of the region.

The soils of Hillah has natural radioactivity which is not high as compared with the average international values as shown in table 7. Radioactive levels of the different regions were measured and the geology and environmental conditions in Hillah are comparable with many regions in the world. Thus, the radiological hazard due to natural radioactivity in Hillah is not only insignificant, but is allowed by the international safety standards. This benchmarking is to validate the research and its overall application.

6. Conclusion

This study is a comprehensive study to investigate the radioactive hazards of the soils collected from three locations at Hillah city in the state of Babylon, namely Matar, Al Magrid and Al Obeid, in order to study the natural radioactivity level in these soils. To provide a valid dataset representative of the natural background of the area, the high-purity germanium (HPGe) gamma spectroscopy was used to determine the particular activity of ^{214}Ra , ^{212}Th and ^{40}K . The average specific activities of ^{214}Ra (31.53 Bq/kg), ^{212}Th (27.33 Bq/kg) and ^{40}K

(409.67 Bq/kg) agree with the globe means and are far lower than the limits where a threat to public health can occur.

Several radiologic markers were computed as a way to give a more comprehensive evaluation of risk. The dosage rate absorbed and yearly effective dosage was determined to be under the international safety standards. Therefore, the dose of external gamma radiation from the these soils is demonstrated to be extremely low. The radium equivalent activity (Raeq) that integrates the possible risks of all the three radionuclides into a single index remained significantly under the acceptable level of 370 Bq/kg. External hazard index (Hex) and internal hazard index (Hin) are measures of the potential of external and internal radiological dangers, respectively. Both were well below unity indicating no appreciable risk due to gamma radiation or inhalation of radon. Also, the computed internal (indoor) and external (outdoor) effective doses were small and the widely recognized radiation weighting factor (Rw) for gamma rays guaranty the accuracy of the biological impacts assessment.

These results are also confirmed by the international comparative studies. It is evident that the soils at Hillah fall within the range of soils predicted for the world as compared to specific activities for other countries like Saudi Arabia, Egypt, Turkey and India.

When measured in the same amount of the same radionuclides found in soils of other locations, the radiation level in the soils of Hillah is not high, and falls well below international safe limits. This comparison not only corroborate the reliability of the present study but also gives more importance to the minimal radiation risk to the residents of Hillah.

Hence, the present study provides baseline data for the city of Babylon, points out the importance of using multiple parameters for environmental radiation assessment and contributes to the monitoring and policy making based on evidence for land use that protects public health in Iraq.

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