Turkish J. Eng. Env. Sci.
32 (2008) , 229 – 234.

Assessment of Human Exposures to Natural Sources of Radiation in Soil of Riyadh, Saudi Arabia

A. S. ALAAMER
Physics Division, Science Department, King Khalid Military Academy,
P.O. Box 22140, Riyadh 11495, SAUDI ARABIA
e-mail: alaamer@hotmail.com

Received 25.03.2008

Abstract

Natural radioactivity is a source of continuous exposure to human beings. It originates from both extraterrestrial sources and radioactive elements in the earth's crust. The amount of radioactivity in soil varies widely. In Riyadh city, the capital of the Kingdom of Saudi Arabia, data on the levels of natural radioactivity in soils is absent. It was therefore considered imperative to measure the activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from various areas of Riyadh city. Activity concentrations were measured by means of high-resolution gamma-ray spectrometry. A total of 100 surface soil samples were collected from all over the Riyadh city. The measured activity concentrations of these radionuclides were compared with the data reported worldwide. Mean measured activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were 14.5±3.9 Bq kg^{-1}, 11.2±3.9 Bq kg^{-1}, and 225±63 Bq kg^{-1}, respectively. Mean values of radium equivalent activity, air absorbed gamma radiation dose rate, and external radiation hazard index were 47.8 Bq kg^{-1}, 23.3 nGy h^{-1}, and 0.13 Bq kg^{-1}, respectively. The annual effective radiation dose was calculated to be 0.14 mSv y^{-1}.

Introduction

The great interest expressed worldwide for the study of naturally occurring radiation and environmental radioactivity has led to the interest of extensive surveys in many countries. Natural sources still contribute almost 80% of the collective radiation exposure of the world's population (UNSCEAR, 1993). There are many sources of radiation and radioactivity in the environment. Gamma radiation emitted from naturally occurring radionuclides, also called terrestrial background radiation, represent the main external source of irradiation of the human body. Human beings are exposed to radiation from sources outside their bodies; mainly cosmic rays and gamma ray emitters in soils, building materials, water, food, and air. Studying the levels of radionuclide distribution in the environment provides essential radiological information.

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world (UNSCEAR, 1993). Natural environmental radioactivity arises mainly from primordial radionuclides, such as ^{40}K, and the radionuclides from ^{232}Th- and ^{238}U-series, which occur at trace levels in all ground formations (Tzortzis et al., 2004). It is important to monitor the terrestrial background radiation mainly due to these natural radionuclides in soil. Several studies performed worldwide have measured the activity concentration of natural radionuclides in soil (McAulay and Morgan, 1988; Quind'so et al.,1994; Ahmed et al., 1997; Karahan et al., 2000; Al-Jundi, 2002; Matiullah et al., 2004; Tahir et al., 2005; Fatima et al., 2008; Saleh et al., 2007). Data regarding levels of natural radioactivity in soils and the corresponding radiation doses to the population are lacking for most parts of Saudi Arabia.

Riyadh, a major part of Riyadh Province, is the capital city of the Kingdom of Saudi Arabia and is located centrally in the Najd region with a popula-

tion expected to reach over 5.2 million in 2007. It is situated in the centre of the Arabian Peninsula on a large plateau on latitude 34°-38° north and longitude 46°-43° east, 600 m above sea level. The area of Riyadh is about 1554 km^2. The weather of Riyadh is predominantly dry and hot with rainfall between the months of January and April. Strong desert winds drive sand and heat to soar during summer and winter can get relatively cold.

The objectives of the present study are to measure the natural radioactivity levels in the surface soils of Riyadh city and to assess the air absorbed external gamma-radiation exposure, annual effective radiation dose, and external radiation hazard index. The data generated in this study will provide base line values of natural radioactivity in soils and may be useful for authorities in the implementation of radiation protection standards for the general population in the country, as well as to conduct further studies on this issue.

Materials and Methods

Soil samples were collected from 25 sites around Riyadh. All sampling sites were preferred to be undisturbed and non-eroded without any influence of man-made structures to ensure that samples were representatives of the sites from where they were taken. From each site, 3-5 soil samples were collected from an area of 0.5 m × 0.5 m up the depth of 25 cm. In this way, a total of 100 soil samples were collected from all 25 sites using a clean trowel, placed in plastic bags, and labeled. Soil samples were passed through a 2-mm mesh sieve to remove stones and other materials. Samples were then air-dried and sieved through a 1-mm mesh sieve. Each sample containing soil grain weighing about 200 g was stored in standardized polyethylene containers. The containers were sealed to avoid any possibility of outgassing of radon and kept for a period of 1 month to make sure the samples attained the radioactive equilibrium between ^{226}Ra with its decay products in the uranium series. It was assumed that ^{232}Th is in secular equilibrium with ^{228}Ra.

For the measurement of activity concentrations of naturally occurring radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples, a high purity germanium (HPGe) detector based gamma ray spectrometer with a relative efficiency of 25% was employed. HPGe detector was coupled with a Canberra multichannel analyzer (MCA). The resolution (FWHM) of the spectrometry system was 1.8 keV at 1332 keV gamma-ray line of ^{60}Co. Spectrum of every sample was collected for 54000 seconds (15 h). Spectrum analysis was performed with computer software and activity concentrations of 3 natural radionuclides were determined. To reduce the background effect, the detector was shielded in a 10 cm wall lead covering lined with 2 mm copper and 2 mm cadmium foils.

The reference materials Soil-6 and RG1 set (obtained from IAEA) have been used for calibration of the spectrometer. The system was calibrated for energy and relative efficiency on a regular basis. The activity concentration of ^{226}Ra was determined by measuring the 186.2 keV peak from ^{226}Ra, 351.9 keV peak from ^{214}Pb, and 609.2 keV peak from ^{214}Bi. The activity concentration of ^{232}Th was determined by measuring 583.1 keV peak from ^{208}Tl and 911.1 keV peak from ^{228}Ac. The activity concentration of 40K was determined using a single peak of 1460 keV. The gamma background level at the laboratory site was determined with an empty plastic container washed with dilute HCl and distilled water. The background was measured under the same conditions of the measurement of the samples. It was later subtracted from the measured gamma-ray spectra of each sample. The activities of ^{226}Ra and ^{232}Th were measured on the assumption that they are in radioactive equilibrium with their respective daughter products. Following the spectrum analysis, count rate for each detected photo peak and activity per mass unit for each of the detected radionuclides was calculated. The activity concentration (in Bq kg^{-1}), AEi, of a radionuclide i and for a peak at energy E, is given by (Tzortzis et al., 2003):

$$A_{Ei} = \frac{C_{Ei}}{c_{eff} \cdot \gamma \cdot m \cdot t} \qquad (1)$$

where C_{Ei} is the total count of a peak at energy E, C_{eff} is the detection efficiency at energy E, t is the counting time, γ is the number of gammas per disintegration of the radionuclide i for a transition at energy E, and m is the mass in kg of the measured sample. If there is more than one peak in the energy analysis range for a nuclide, then an attempt to average the peak activities is made. The result is then the weighted average nuclide activity (Tzortzis et al., 2003). The activity concentration of each of the 3 radionuclides was finally measured in Bq kg^{-1}. The total uncertainty of the measured activity concentration, absorbed dose rate, and other indices were within 3%–8%.

Assessment of radiation hazards

Radium equivalent activity The radiation hazards associated with the radionuclides are estimated by calculating the radium equivalent activity (Ra_{eq}). It is a weighted sum of activities of ^{226}Ra, ^{232}Th, and ^{40}K; and it is based on the assumption that 370 Bq.kg^{-1} of ^{226}Ra, 259 Bq.kg^{-1} of ^{232}Th, and 4810 Bq.kg^{-1} of ^{40}K produce the same gamma radiation dose rate (Matilullah et al., 2004; Fatima et al., 2008). To avoid radiation hazards, materials whose Ra_{eq} is greater than 370 Bq kg^{-1} should not be used. Ra_{eq} is defined by the following formula:

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

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

Air absorbed gamma radiation dose rate

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The activity concentrations in soil correspond to the total absorbed dose rate in air at 1 m above the ground level. The absorbed dose rate in air (D) for the population living in the studied area is calculated using the following equation (Matilullah et al., 2004; Fatima et al., 2008):

$$D = (F_{Ra} \cdot A_{Ra} + F_{Th} \cdot A_{Th} + F_K \cdot A_K) \times 10^{-6} \quad (3)$$

where D is the absorbed dose rate in air (nGy h^{-1}) at 1 m height above the ground level. F_{Ra}, F_{Th}, and F_K are the dose conversion factors for ^{226}Ra, ^{232}Th, and ^{40}K, respectively. They are taken as 4.27, 6.62, and 0.43 for ^{226}Ra, ^{232}Th, and ^{40}K, respectively as assessed by UNSCEAR (UNSCEAR, 1993).

Annual effective dose The annual effective dose received by the population is calculated using the following formula (UNSCEAR, 2000):

$$E = T \cdot Q \cdot D \times 10^{-6} \quad (4)$$

where D is the absorbed dose rate in air, Q is the conversion factor of 0.7 Sv Gy^{-1}, which converts the absorbed dose rate in air to human effective dose received (UNSCEAR 2000), and T is the time for 1 year, i.e. 8760 hrs.

External radiation hazard index External radiation hazards due to natural radionuclides of ^{40}K,^{232}Th, and ^{226}Ra are defined in terms of external or outdoor radiation hazard index denoted by H_{ex}. It is computed by the following expression:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

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

Results and Discussion

The mean values of measured activity concentrations of selected radionuclides of ^{226}Ra, ^{232}Th, and^{40}K in soil samples from all 25 sites in Riyadh are shown in Table 1. The activity concentrations of ^{226}Ra, ^{232}Th, and^{40}K are in the range of 10.8–29.7 Bq kg^{-1}, 7.4–25.3 Bq kg^{-1}, and 98–320 Bq kg^{-1} with a mean value of 14.5±3.9, 11.2±3.9, and 225±63 Bq kg^{-1}, respectively. The measured activity concentrations of ^{226}Ra, ^{232}Th, and^{40}K were compared with the values reported worldwide (McAulay and Morgan 1988, Ziqiang et al., 1988, Baeza et al., 1992, Sam et al., 1997, Mustapha et al., 1999, UNSCEAR 2000, Narayana et al., 2001, Tzortzis et al., 2004, Arogunjo et al., 2004, Tahir et al.,2005, Fatima et al., 2008, Saleh et al., 2007) as shown in Table 2. It is found that the measured activity concentrations of 3 naturally occurring radionuclides in this study are lower than most of the reported values from other countries as well as the world's average values. In order to ascertain the existing ratio between the activity concentrations of 3 radionuclides in soil samples, correlations amongst them are drawn using the regression technique. In all 3 cases, the regression between the activity concentration of ^{226}Ra and ^{232}Th, ^{226}Ra and ^{40}K,;nd ^{232}Th and ^{40}K was calculated with correlation a coefficient of 0.89, 0.48, and 0.34, respectively. The results shown in Table 1 also indicate that the mean value of ^{232}Th (11.2±3.9 Bq kg^{-1}) < ^{226}Ra (14.5±3.9 Bq kg^{-1}) <^{40}K (225±63 Bq kg^{-1}).

Radium equivalent activity (Ra_{eq}) owing to activity concentration of 3 natural radionuclides from all sites varies from 28.9 to 95.5 Bq kg^{-1}. The mean value of Ra_{eq} is 47.8 Bq kg^{-1}, which is much less than the threshold value of 370 Bq kg^{-1}. The mean values of air absorbed gamma radiation dose rate (D), annual effective dose (E), and external radiation hazard index (H_{ex}) calculated in this work are shown in Table 3. It is shown that mean values of D, E, and H_{ex} are 23.3 nGy h^{-1}, 0.14 mSv y^{-1}, and 0.13, respectively. Mean annual effective radiation dose of 0.14 mSv y^{-1} computed in this work is much less than the dose rate reported worldwide.

Table 1. Activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples.

Site	No. of samples	^{226}Ra	^{232}Th	^{40}K
S1	4	14.2 ± 1.8	8.8 ± 1.2	211 ± 26
S2	4	12.8 ± 1.6	10.5 ± 1.5	108 ± 14
S3	4	11.6 ± 1.5	7.9 ± 0.9	220 ± 26
S4	4	13.4 ± 1.7	10.7 ± 13	198 ± 25
S5	4	16.8 ± 2.4	13.1 ± 1.5	270 ± 36
S6	4	24.2 ± 3.1	21.4 ± 2.9	304 ± 39
S7	5	25.3 ± 3.4	17.4 ± 2.2	320 ± 44
S8	4	20.5 ± 2.7	16.3 ± 2.0	296 ± 38
S9	3	15.2 ± 2.0	11.1 ± 1.3	243 ± 31
S10	3	12.2 ± 1.6	9.8 ± 1.2	265 ± 33
S11	4	11.9 ± 1.6	8.5 ± 1.1	188 ± 24
S12	4	15.6 ± 1.9	11.6 ± 1.5	145 ± 16
S13	4	11.4 ± 1.5	9.7 ± 1.2	158 ± 20
S14	4	12.1 ± 1.6	7.9 ± 1.0	217 ± 25
S15	4	11.5 ± 1.4	7.8 ± 1.1	232 ± 28
S16	4	16.5 ± 2.1	12.7 ± 1.6	274 ± 36
S17	5	13.3 ± 1.7	7.6 ± 0.9	248 ± 31
S18	4	11.5 ± 1.5	8.0 ± 1.1	279 ± 36
S19	4	16.2 ± 2.1	15.5 ± 2.0	98 ± 13
S20	5	10.8 ± 1.3	7.4 ± 1.0	123 ± 16
S21	4	13.4 ± 1.7	13.5 ± 1.7	182 ± 24
S22	3	11.8 ± 1.5	8.1 ± 1.1	231 ± 30
S23	4	11.9 ± 1.5	9.1 ± 1.2	280 ± 33
S24	4	17.2 ± 2.3	18.2 ± 2.5	300 ± 39
S25	4	11.1 ± 1.4	7.4 ± 1.0	235 ± 28
Range		10.8-29.7	7.4-25.3	98-320
Mean		14.5 ± 3.9	11.2 ± 3	225 ± 63

Table 2. Activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K measured worldwide.

Country	^{226}Ra	^{232}Th	^{40}K	Reference
Alexandria, Egypt	16.7 ± 2.7	19.4 ± 5.0	262 ± 82	Saleh et al., 2007
Cyprus	7.1 ± 8.6	5.0 ± 7.1	105 ± 95	Tzortzis et al., 2004
Sudan	28.31	20.12	280.29	Sam et al., 1997
Punjab, Pakistan	35 ± 7	41 ± 8	615 ± 143	Tahir et al., 2005
Southern Punjab, Pakistan	21.7 ± 4.4	31 ± 6.6	393.2 ± 83.2	Fatima et al., 2008
South India	35	29.8	117.5	Narayana et al., 2001
Spain	46	49	650	Baeza et al.,1992
Nigeria	16.2 ± 3.7	24.4 ± 4.7	34.8 ± 20.4	Arogunjo et al.,2004
Kenya	28.7 ± 3.6	73.3 ± 9.1	255.7 ± 38.5	Mustapha et al., 1999
China	42.7 ± 15	46.3 ± 12	578 ± 164	Ziqiang et al., 1988
Republic of Ireland	60	26	350	McAulay and Morgan, 1988
Saudi Arabia	14.5 ± 3.9	11.2 ± 3.9	225 ± 63	Present Study, 2007
World's average	35	30	400	UNSCEAR, 2000

Table 3. Mean value of air absorbed gamma radiation dose rate (D), annual effective dose (E), and external radiation hazard index (H_{ex}).

Location	D (nGy h^{-1})	E (mSv y^{-1})	H_{ex} H_{ex}
Riyadh, Saudi Arabia	23.3	0.14	0.13

Conclusion

The present study has been carried out to establish baseline data regarding concentration levels of naturally occurring radionuclides of ^{226}Ra, ^{232}Th, and^{40}K in soils and the corresponding radiation doses in Riyadh, Saudi Arabia. Measured mean activity concentrations of the 3 radionuclides are found to be less than the world's average values. Calculated values of external radiation doses are also lower than the world average of about 0.5 mSv per year. To estimate the potential radiological health risk in soil, the dose rate associated with ^{137}Cs in soils of area studied should be investigated as well. However, the data generated here may be useful for the introduction of radiation safety standards by the authorized organizations for the protection of general population from radiation hazards owing to terrestrial sources.

References

Ahmad, N., Matiullah, and Khatibeh, A.J.A.H., "Indoor Radon Levels and Natural Radioactivity in Jordanian Soils", Radiat. Prot. Dosimetry 71, 231-233, 1997.

Al-Jundi, J., "Population Doses from Terrestrial Gamma Exposure in Areas Near to Old Phosphate Mine, Russaifa, Jordan", Radiation Measurements 35 (1), 23-28, 2002.

Arogunjo, A.M., Farai, I.P. and Fuwape, I.A., "Dose Rate Assessment of Terrestrial Gamma Radiation in the Delta Region of Nigeria", Radiat. Prot. Dosimetry 108, 73-77, 2004.

Baeza, A., del Rio, M., Mir, C., Paniagua, J.M., "Natural Radioactivity in Soils of the Province of Caceres (Spain)", Radiat. Prot. Dosimetry 45, 261-263, 1992.

Fatima, I., Zaidi, J.H., Arif, M., Daud, M., Ahmad, S.A., Tahir, S.N.A., "Measurement of natural radioactivity and dose rate assessment of terrestrial gamma radiation in the soil of southern Punjab, Pakistan", Radiat. Prot. Dosimetry, 128(2), 206-212, 2008.

Karahan, G. and Bayulken, A., "Assessment of Gamma Dose Rates Around Istanbul, Turkey", J. Environmental Radioactivity 47 (2), 213-221, 2000.

Matiullah, Ahad, A., Ur Rehman, S., Ur Rehman, S. and Fahee, M., "Measurement of Radioactivity in the Soil of Bahawalpur Division, Pakistan", Radiat. Prot. Dosimetry 112 (3), 443-447, 2004.

McAulay, I.R. and Morgan, D., "Natural Radioactivity in Soils in the Republic of Ireland", Radiat. Prot. Dosimetry 24 (1/4), 47-49. 1988.

Mustapha, A.O., Patel, J.P. and Rathore, I.V.S., "Assessment of Human Exposures to Natural Sources of Radiation in Kenya", Radiat. Prot. Dosimetry 82, 285-292, 1999.

Narayana, Y., Somashekarappa, H.M., Karunakara, N., Avadhani, D.N., Mahesh, H.M.and Siddappa, K., "Natural Radioactivity in the Soil Samples of Coastal Karnataka of South India", Health Physics. 80 (1), 24-33, 2001.

Quind'os, L.S., Fernandez, P.L., Soto, J., R'odenas, C.and Comez, J., "Natural Radioactivity in Spanish Soils", Health Physics 66, 194-200, 1994.

Saleh, I.H., Hafez, A.F., Elanany, N.H., Motaweh, H.A.and Naim, M.A., "Radiological Study on Soils, Foodstuff and Fertilizers in the Alexandria Region. Egypt" Turkish J. Eng. Env. Sci. 31, 9-17, 2007.

Sam, A.K., Ahmed, M.M.O., El Khangi, F.A., El Nigumi, Y.O. and Holm, E., "Assessment of Terrestrial Gamma Radiation in Sudan", Radiat. Prot. Dosimetry 71 (2), 141-145, 1997.

Tahir, S.N.A., Jamil, K., Zaidi, J.H., Arif, M., Ahmed, N.and Ahmad, S.A., "Measurements of Activity Concentrations of Naturally Occurring Radionuclides in Soil Samples from Punjab Province of Pakistan and Assessment of Radiological Hazards", Radiat. Prot. Dosimetry 113 (4), 421-427, 2005.

Tzortzis, M., Svoukis, E. And Tsertos, H., "A Comprehensive Study of Natural Gamma Radioactivity Levels and Associated Dose Rates From Surface Soils in Cyprus", Radiat. Prot. Dosimetry 109, 217-224, 2004.

Tzortzis, M., Tsertos, H., Christofides, S.and Christodoulides, G., "Gamma-Ray Measurements of Naturally Occurring Radioactive Samples from Cyprus Characteristic Geological Rocks", Radiation Measurement 37 (3) 221-229, 2003.

United Nations Scientific Committee on Effects of Atomic Radiation, "Sources and Effects of Ionising Radiation", UNSCEAR Report, New York, 1993.

United Nations Scientific Committee on Effects of Atomic Radiation, "Exposures from natural radiation sources", UNSCEAR, 2000.

Ziqiang, P., Yin, Y. and Mingqiang, G., "Natural Radiation and Radioactivity in China", Radiat. Prot. Dosimetry 24 (1/4), 29-38. 1988.