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RADIOMETRIC CHARACTERIZATION OF SAND IN NORTHEAST SINAI, EGYPT

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Abstract

Thirty–eight locations covering an area of about 350 km^2 in northeast Sinai were investigated by γ–ray spectroscopy using a 50% HPGe detector. The area is limited by Al–Arish city North, El–Hasana South, El–Oga East, and El–Gifgafa West. The ranges of activity concentrations of ^{238}U, ^{234}Th, ^{226}Ra, ^{232}Th and ^{40}K are 0.6–35.2, 3.9–22.6, 4.7–29.6, 4.7–23.9, and 108–295 Bq kg^{-1} for sand samples, respectively. Also, the range of ^{137}Cs concentrations is 0.1–8.0 Bq kg^{-1}. No major difference between the studied area and that previously investigated in the costal area of North Sinai. Reliable correlations (R = 0.8–0.9) among ^{238}U, ^{234}Th, and ^{226}Ra isotopes were obtained. On the other hand, low correlations (R = 0.6–0.7) were obtained from the analysis of the isotopes of ^{238}U–series and that of ^{232}Th. No evidence of correlation was found between the concentrations of radioisotopes and the sand characteristics; i.e. pH, grain size, and the contents of total organic matter (TOM), bicarbonate, calcium carbonate. The wild vegetations collected from the studied area have average concentrations of 0.73, 1.11, 1.26, 254, and 0.31 for ^{234}Th, ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs, respectively. The soil–plant transfer factors were 0.21, 0.15, 0.18, 1.52 and 0.74 for ^{234}Th, ^{226}Ra and ^{232}Th, ^{40}K, and ^{137}Cs, respectively. The average concentrations of ^{226}Ra, ^{232}Th, and

^{40}K in water samples collected from five wells are 0.08, 0.06 and 1.06 Bq l^{-1}, respectively. The average absorbed dose rate for the sand samples were calculated to be 19.4 nGy h^{-1}. The Ra_{eq} activities of the sands are lower than the recommended maximum value of 370 Bq kg^{-1} criterion limit of Ra_{eq} activity for building materials.

Keywords: *Natural radionuclides, Sinai, Egypt.*

1. INTRODUCTION

Natural radiation arising from the Earth's crust is the largest contributor to the external dose of the world's population which increase the external exposure and inhalation or ingestion of natural radionuclides. According to UNSCEAR (1993) [1], about 87% of the radiation dose received by mankind is due to natural radiation sources, which are mainly due to the activity concentration of primordial radionuclides ^{232}Th, ^{238}U and their products of decay, in addition to ^{40}K present in the Earth' crust (UNSCEAR, 2000) [2]. Knowledge of the distribution of radionuclides enables one to assess any possible radiological risks to human health. The great interest for the study of naturally occurring radioactive materials (NORM) activity has led to the performance of extensive surveys in many countries of the world [2]. Such investigations can be useful for keeping reference data records, in order to ascertain possible changes in environmental radioactivity due to nuclear, industrial, and other human activities.

The main aim of the present work is to determine the NORM levels in dune sand in northeast Sinai area. It also aims to provide information about the dependence of the radioisotope concentrations on the samples characteristics like pH, grain size, TOM content, bicarbonate and calcium carbonate. The wild vegetations collected from the studied area are also investigated, including the soil–plant transfer factor. Dosimetric evaluation for risk of human exposure is estimated using different radiation hazard indices: radium equivalent, Ra_{eq} [3], absorbed dose rate [4], and annual effective dose equivalent [2].

2. MATERIALS AND METHODS

2.1 Study Area

Figure 1 shows the geographic location of the study area in Northeast Sinai Peninsula, Egypt. The study area lies between 33° 22' to 34° 26' E longitudes and 30° 27' to 31° 05' N latitude. The surveyed area was about 350 km^2. It plays an important role in coal mining and cement manufacturing because of its wide variety in its geological surface formations. A total of 38 sites were included in this study (see Fig. 1). Dune sand, plant and water samples were collected in December, 2007 including locations in Al–Maghra mountain (sites 1–4), Baghdad village (sites 14–19), El–Hassana town (sites 37–38), Abu–Aweigila village and El–Oga (sites 21–28), El–Qusima town (sites 29–36) and surrounded areas.

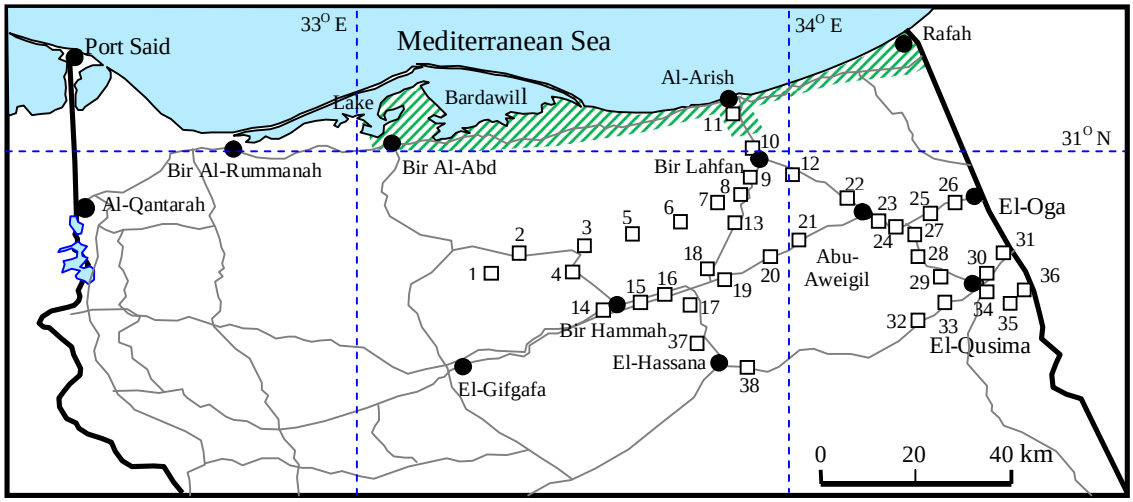

Fig. 1. The map of the study area in Northeast Sinai, Egypt. The 38 locations of the collected samples are shown as open squares. Only water samples are collected from locations numbers 23 and 34 and sand samples are collected from the remaining 36 locations. Towns are also shown as closed circles.

2.2 Sampling

The sampling sites have been selected to cover the whole area as uniformly as possible. The distance between two successive locations varied from 10 km to 15 km depending on various factors. Among the major deciding factors were the site accessibility and the undisturbed appearance. Sampling sites were selected to be open, reasonably level and not obviously prone to flooding or other natural disturbance. GPS was used to record the latitude and longitude of the selected sites.

Dune sand samples (~3 kg each) were collected from undisturbed flat area of about 10×10 m^2, form five cores down to 10 cm of the surface layer. Water samples (~20 Liters) were collected and acidified with hydrochloric acid to avoid adsorption of nuclides on the water container. Plant samples (~7 kg fresh weight) collected from the area are abundant wild plants (see table 1). The various kinds of collected samples were transported to Radioanalysis Research Laboratory (RRL), Faculty of Science, Tanta University, Tanta, Egypt for analysis.

2.3 Sample Preparation

The sand and plant samples were air dried and hand–cleaned. The samples obtained were oven dried at 90 °C until reach a constant mass, homogenized, ground in case of plant samples, and sieved with 2 mm sieve. In the case of water samples, each sample was evaporated using a hot plate until its volume reached ~1 liter at 90°C. The water was then left to cool at which point it was packed. All the perpetrated samples were placed in PVC cylindrical container of a diameter ~17 cm and height ~9.5 cm. The containers were sealed tightly with a thick vinyl tape to limit gas escape from them, and

stored for a minimum period of 4 weeks to allow radioactive equilibrium between ^{226}Ra, ^{222}Rn and its daughter products.

Table 1. Location numbers and family, common and scientific names of wild plant samples.

Location Number	Family name	Common name	Scientific name	Economic Important
3, 20, 32	Thymelaeaceae	Mithnaan, mitnaan	Thymelaea hirsuta	Grazing, Fuel, Medicinal use
6, 4, 24, 25	Polygonaceae	Arta, Teeb, Risoo	Calligonum comosum	Medicinal use
9	Chenopodiaceae	Oilwe, Gilwe, Qalye	Anabasis articulata	Grazing, Fuel, Medicinal use
13	Chenopodiaceae	Suaeda	Suaeda pruinosa	Medicinal use
18, 22, 29, 38	Zygophyllaceae	Ratreyt, rotreyt, balbal	Zygophyllum album	Grazing, Medicinal use
26, 36	Caryophyllaceae	Hairy rupture – Wort	Herniaria hirsuta	Medicinal use
28, 33	Chenopodiaceae	Had	Cornulaca monacantha	Grazing, Medicinal use

Characteristics of sand samples, pH, TOM content and grain size fractions were investigated. Water samples salinity, pH and bicarbonate concentration were also determined. Soil pH is one of a number of environmental conditions that affect the quality of plant growth. Among the important reasons for measuring the pH is that it may influence the mobility of radionuclides in the ground because it affects the adsorption process and the solubilization of radionuclides. By similarity, the salinity, bicarbonate and TOM content characteristics may affect the mobility of different elements in the environment.

2.4 Activity Measurements

The activity concentrations of radioisotopes in the studied samples were measured using the 50% p–type closed–end coaxial HPGe detector (Canberra). It has an energy resolution (FWHM) of 1.89 keV for the 1332.5 keV ^{60}Co γ-line. The detector was shielded using a 10 cm thick low–background lead shield (Canberra 747E). The amplified signals of HPGe detector was acquired with 16 K ADC MCA (Canberra, Genie 2000). The measuring times were ranged from 18,000 to 200,000 s to provide adequate counts under the various γ–ray photopeaks. The energy and efficiency calibrations have been done as mentioned in Refs [5,6].

The 92.4 and 92.8 keV γ–rays were used to determine the activity of ^{234}Th which is assumed to be in radioactive equilibrium with ^{238}U. ^{222}Rn concentrations were calculated as the weighted average of the activity determined using the γ–ray lines 295.2 and 351.9 keV of ^{214}Pb and 609.3, 1120.3, 1764.5 and 2204.1 keV of ^{214}Bi. ^{226}Ra was assumed to be in radioactive equilibrium with ^{222}Rn. The γ–ray photopeaks used for the determination of the ^{232}Th contents were 911.2, 964.6, 969.0 and 1588.2 keV of ^{228}Ac, 727.3 and 1620.7

keV of ^{212}Bi, 238.6 keV of ^{212}Pb and 583.2, 860.6 and 2614.5 of ^{208}Tl. ^{40}K and ^{137}Cs were directly determined using 1460.8 and 661.7 keV γ–rays, respectively.

3. RESULTS AND DISCUSSIONS

3.1 Characteristics of Samples

The pH values of the sand samples had a range of 7.8–10.0 with an average value of 8.8±0.5. The present data did not allow testing of this possible effect because of the limited range of the samples' pH. Figure 2 shows the mean contribution of individual grain size fractions for sand samples. Sand samples are rich in the grain sizes ranged from 0.125 to 0.5 mm which represents about 70% of the samples. The TOM content was found to be less than 5% for sand samples, except 4 samples which had TOM values between 6.1 and 9.8%. The TOM content range was (0.20–9.8%) with an average value of 2.36%±2.53.

Water samples salinity had a range of 108–513 mg l^{-1} with an average value of 361±154 mg l^{-1}. The water pH range was 8.45–8.72 with an average value of 8.59±0.11. The bicarbonate concentration ranged from 195 mg l^{-1} to 415 mg l^{-1} with an average value of 294±91 mg l^{-1}. The narrow ranges of the present parameters did not allow testing of their influence on the mobility of radionuclides in the ground.

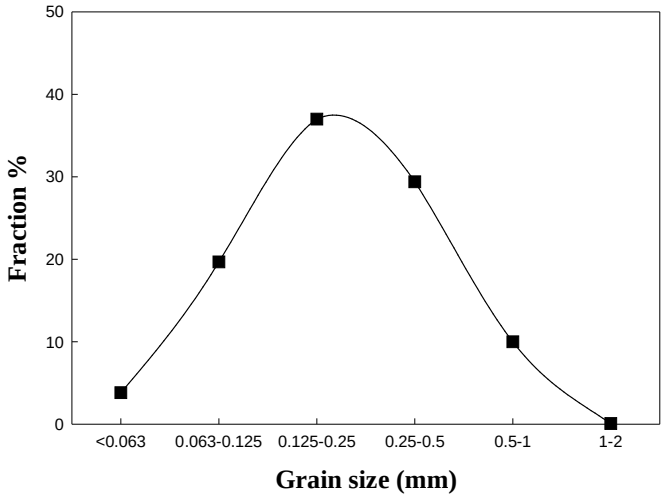

Fig. 2. The mean contribution of individual grain size fractions for sand samples.

3.2 Activity Concentrations

The activity concentrations of ^{235}U, ^{238}U, ^{234}Th, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in Bq kg^{-1} dry weight (DW), for sand and plant samples, and in Bq l^{-1} for water samples, for each single site are shown else where [7]. The average activities and ranges for each sample type in the studied area are given in Table 2.

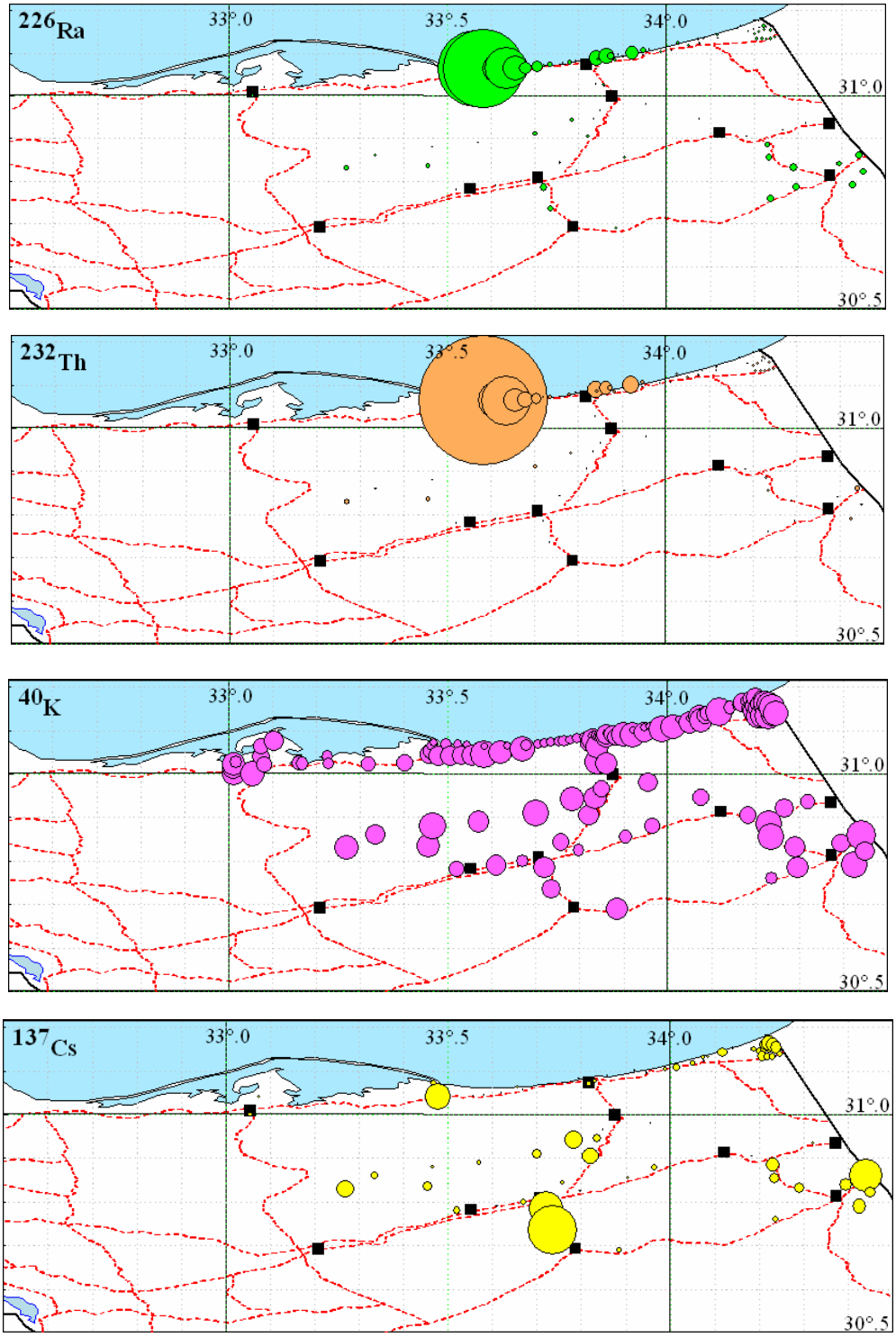

Fig. 3. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in sand samples of the studied area and that of a previous study [8]. The circles represent the activity concentrations at each location with radii linearly proportional to the activity concentrations value.

For sand samples, the average activity concentrations of ^{235}U, ^{238}U, ^{234}Th, ^{226}Ra and ^{232}Th were 0.51±0.38 Bq kg^{-1} (0.03–1.63 Bq kg^{-1}), 10.9±8.1 Bq kg^{-1} (0.59–35 Bq kg^{-1}), 10.2±5.2 Bq kg^{-1} (3.9–23 Bq kg^{-1}), 13.1±7.8 Bq kg^{-1} (4.7–29.6 Bq kg^{-1}) and 9.3±4.9 Bq kg^{-1} (4.7–24 Bq kg^{-1}), respectively. The range of the activity concentrations of ^{40}K in sand samples were 108–295 Bq kg^{-1} with an average value of 178±39Bq kg^{-1}. The man–made radionuclide ^{137}Cs was also present in measurable concentrations in all samples. The concentrations of ^{137}Cs ranged from 0.12 to 8.04 Bq kg^{-1} with an average value of 1.57±1.70 Bq kg^{-1}. The present results of sand are in the same range as those obtained from North Sinai [8] and Nile delta and middle [9,10]. However, the activity concentrations in the present study for both ^{226}Ra and ^{232}Th are slightly lower than sand used as building material in Egypt [11], while ^{40}K is higher than sand used as building material in Egypt [11,12]. The present results of dune sand are also comparable with those from Jordan [13], Libya [14] and Lebanon [15].

Table 2. The average activity concentrations of NORM and ^{137}Cs in sand, plant (in Bq kg^{-1} DW) and water samples (in Bq l^{-1}).

Sample Type	^{235}U	^{238}U	^{234}	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Sand							
Mean	0.51±0.38	10.9±8.1	10.2±5.2	13.1±7.8	9.3±4.9	178±39	1.57±1.70
Range	0.03–1.63	0.59–35	3.9–23	4.7–29.6	4.7–24	108–295	0.12–8.04
Plant							
Mean				1.11±1.0	1.26±0.55	254±131	0.31±0.20
Range				<MDA–3.1	0.56–2.6	102–624	<MDA–0.68
Water							
Mean			0.19*	0.08±0.07	0.06±0.05	1.06±0.54	
Range			—	0.02–0.16	0.02–0.13	0.33–1.62	

*one sample.

Figure 3 shows the activity concentrations in sand samples from the present investigation combined with that obtained in the previous study [8] (total of 100 locations). The circles represent the activity concentrations at each site with radii linearly proportional to the activity concentrations.

Reliable correlations (R^2 = 0.8–0.9) among ^{238}U, ^{234}Th, and ^{226}Ra isotopes were obtained. On the other hand, low correlations (R^2 = 0.6–0.7) were obtained from the analysis of the isotopes of ^{238}U–series and that of ^{232}Th. No evidence of correlation was found between the concentrations of radioisotopes and the sand characteristics; i.e. pH, grain size, and the contents of TOM, bicarbonate, calcium carbonate.

Results of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs concentrations in different plant species are estimated. The mean activity concentrations were for ^{226}Ra, 1.11±1.0; ^{232}Th, 1.26±0.55 and ^{40}K, 254±131 Bq kg^{-1}. The mean activity concentration of ^{137}Cs was 0.31±0.20 Bq kg^{-1}. ^{40}K exhibits variability in vegetation samples ($1\sigma \approx 51\%$). The activity concentrations of ^{137}Cs in natural vegetations were low and nearly equal. Generally, the activity concentration in vegetation is comparable with the activity concentration in Lake

Burullus [16]. Vegetation samples from the northwestern area of the delta in Egypt had higher concentrations than that of the present study ranging from below the detection limit up to 41.7, 14.1, 2416, and 11.9 Bq kg^{-1} for ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs, respectively [17]. The present results of ^{40}K are well contained in the range of 12–797 Bq kg^{-1} obtained from various species of natural vegetation from the environment of Kaiga, India [18].

The radioactivity contents in both soil and vegetation samples were used to evaluate the soil–plant transfer factor (TF), which is defined as:

$$TF = \frac{\text{Radioactivity in plant (Bq kg}^{-1}\text{ DW)}}{\text{Radioactivity in soil (Bq kg}^{-1}\text{ DW)}}$$

The soil–plant transfer factors were 0.21±0.08 (0.14–0.34), 0.15±0.19 (0.03–0.66), 0.18±0.11 (0.07–0.55), 1.52±0.82 (0.75–3.57), 0.74±1.05 (0.05–3.61) for ^{234}Th, ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs, respectively. The mean TFs of the five radionuclides show significant differences, particularly in comparison between Cs and K. The TFs are generally higher for ^{40}K than the rest of radionuclides. No evidence correlation was found between the TFs of ^{137}Cs and that of ^{40}K. ^{40}K TFs of wild plants ranged from 0.87 to 2.12 in lake Burullus, Egypt [16]. Its range in fruit trees was (0.7–2) for leaves and (0.7–1.5) for fruits in Syria [19], (1.4–6.2) for Colocassia esculenta and Chromolaena odorata in India [20], (0.16–2.42) for grass in Greece [21], and (0.09–0.44) for different plant kinds in Bulgaria [22]. The TFs for ^{137}Cs show wide variation which may be considered as an indication of change of soil characteristics and/or physical and plant physiological processes in the studied area. The ^{137}Cs TFs to wild plants ranged between 0.03 and 1.58 in Lake Burullus, Egypt [16].

The average concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in water samples collected from five wells are 0.08 (0.02–0.16), 0.06 (0.02–0.13), and 1.06(0.33–1.62) Bq l^{-1}, respectively. The present results of ^{40}K are are nearly the same as that obtained for the north Sinai previous study, 0.98±1.91 (0.4–1.8) Bq l^{-1} [8].

3.3 Dosimetry Assessment

The resulting radium equivalent, absorbed dose rate and effective dose equivalent are estimated for each sand samples. The average value of the radium equivalent was 40.0±15.3 (22.4–72.5) Bq kg^{-1}, which is far below the maximum of 370 Bq kg^{-1}. The average value of the absorbed dose rates was 19.4±7.05 (11.0–34.6) nGy h^{-1}, which is below the cited value 59 (18–93 nGy h^{-1}) [2]. The average value of effective dose equivalents was 24.5±8.9 (13.8–43.6) µSv a^{-1} which also far below that of the world average value of 410 µSv a^{-1} [4].

4. CONCLUSIONS

The narrow ranges of the present data for samples' characteristics did not allow testing of their influence on the mobility of radionuclides in the ground. The activity concentrations of NORM and ^{137}Cs in sand samples are in the same range as those obtained from North Sinai and different regions of Egypt. The wide variation of ^{137}Cs TFs may indicate the change of soil characteristics and/or physical and plant physiological processes in the area. The resulting radium equivalent, absorbed dose rate and effective dose equivalent are far below the cited values and the world average values. The Ra_{eq} activities of the sands are lower than the recommended maximum value of 370 Bq kg^{-1} criterion limit of Ra_{eq} activity for building materials.

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