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Measurement of Natural Radioactivity in Soil Samples from Some Areas of Sharjah by Gamma-Ray Spectrometry

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Abstract

Activity survey of Naturally Occurring Radioactive Materials (NORMs) in surface soil, took place at selected areas in the city of Sharjah, United Arab Emirates (UAE). Twenty-five composite soil samples were collected from five selected regions in Sharjah city, adhering to the procedures laid out by the International Standards Organization (ISO). By utilizing a gamma-ray spectrometry system with a Broad Energy Germanium detector (BEGe), the activity concentrations of 238U, 232Th, and 40K were determined in Bq/kg. Respectively, the activities ranged from 6.27 ± 0.28 to 56.23 ± 0.47, from 0.84 ± 0.11 to 7.10 ± 0.28, and from 29.40 ± 2.82 to 200.49 ± 8.91. From these concentrations, the outdoor absorbed dose rates, radiation hazard Indices, Gamma index and radium equivalent activity were calculated. Wind statistics were also employed to assure that collected surface soil represents the sampled regions. The study concluded that all samples from selected regions emit low-intensity natural terrestrial radiation, which poses no immediate health risks, and is insignificant in comparison to the world's average values stated by the United Nations Scientific Committee in 2008.

***Keywords:** Natural Radioactivity; Dose Rates; External Hazard Index; Terrestrial Radiation; Gamma Spectroscopy; Radium Equivalent*

Introduction

Living organisms including humans can be exposed to radiation following various pathways. Therefore, it is unquestionably important to obtain some information from the environment, from which the exposure to humans can be evaluated. One way to represent such information is to map the possible pathways in which radioactive exposure can reach humans. A pathway of exposure flows from a radioactive source to humans through the environment itself or living organisms in the environment [1].

The origin of natural radiation found to be terrestrial and extra-terrestrial radiation. The terrestrial radiations were formed in Earth's crust due to naturally occurring radioisotopes (NORMs) presented in varying amount in water, rocks and mainly in the soil. The extra-terrestrial radiation, however, includes the cosmic radiation formed in space [2].

Investigation of soil radioactivity is crucial for the evaluation of the aftereffects of a possible release of radioactive substances in the environment as well as its inhabitants, which can take place through internal or external pathways. Based on UNSCEAR 2000 guidelines, the soil is considered the main source for natural radioactivity due to terrestrial radiation or

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naturally occurring radioisotopes (primordial radionuclides) such as Potassium-40 (40K), Thorium-232 (232Th) and Uranium-238 (238U). The most of the external exposure of x or gamma rays are related to 40K, 232Th and 238U which are available in different levels of soil [3]. However, the variation of natural radioactivity and the external exposure differ from one place to another depending on different criteria such as geological and geographical conditions [4]. It is important to measure natural radioactivity in an environment to establish a reference level, to be used for radiometric mapping, and to determine the amount of change of the natural background activity with time [5].

There are no systematic data on this subject available for Sharjah. Therefore, the objective of the present study is to estimate the activity concentration of the terrestrial gamma radiation (uranium, thorium, and potassium) in selected regions of Sharjah City to provide a reference for future-mapping of the city and its surroundings.

NORMs are excited and will undergo successive radioactive decays to reach equilibrium, ultimately arriving at stable daughter nuclei(s). Over time, the concentration of NORMs will decline, whereas that of their emerging daughters will rise. Therefore, proper sample preparation as well as adequate storage time, are vital prior to perform Gamma-ray based activity concentration analysis. The results of these measurements will pave the way to quantifying absorbed dose rates, effective dose rates, hazard and gamma indices and radium equivalent activities.

Materials and Methods

The study aims to monitor selected regions in the city of Sharjah to obtain an idea about the natural background radioactivity levels in the city. With emphasis on the word natural, sampling sites to be avoided are ones within close proximity to highways, rural roads, residential buildings, agricultural fields containing artificial fertilizers and industrial regions such as power plants

Since we are not after the generation of a database for future reference, random sampling approach was taken which involves choosing random points within the region of interest, which are then surface soil samples were collected. All collected soil samples were stamped with identification labels that indicate each sample's region, number, and geographic coordinates.

Sample collection

A total of twenty-five samples were collected randomly from five different locations in Sharjah, UAE, as shown in **FIG. 1,** sampled in a depth of 10 cm. For our samples to meet the study of natural radioactivity in the region, no sampling site was taken close to a building, a road, a tree, a field boundary or other obstructions as recommended by the International Organization for Standardization (ISO) [6]. The soil samples were collected using a Composite Sampling Methodology which strategically allows for the combination of three samples into one from the edges of an equilateral triangle as shown in **FIG. 2,** every three subsamples approximately weigh 2 kg.

The samples were housed and transported in well-sealed plastic bags, and the sample name and region number were recorded along with the GPS coordination of the sampling point which was obtained using Canberra Colibri VLD. These coordinates were later used to indicate the position on the map by dark blue squares.

FIG .1**. Soil sites, with actual sample coordinates.**

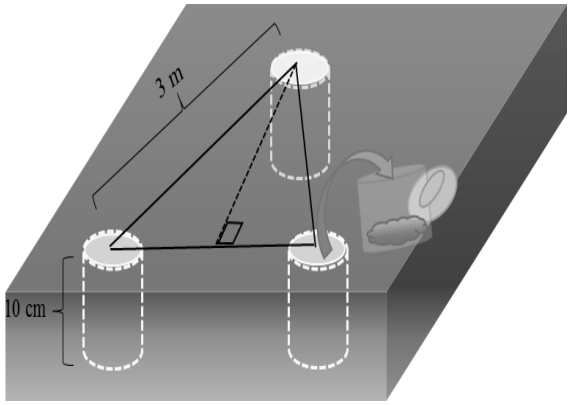

FIG. 2. **The Composite Sampling Methodology.**

Sample preparation

Collected soil samples were taken to the university laboratories and were dried in the oven at 105 ℃ for a day. Next, they were homogenized by sieving to obtain particles with the target size of 200 μm, as well as to remove any to stones and pebbles. Then the soil samples were weighed and placed in cylindrical polypropylene bottles, of 500 ml volume, each. These bottles were sealed with aluminum foils to prevent any escape of Radon (^{222}Rn) and Thoron (^{220}Rn) gas, as well as to prevent any air or humidity from entering the samples. The samples were then stored for approximately four weeks to allow reaching a secular equilibrium among progenies of ^{232}Th and ^{238}U series.

Gamma-ray analysis

Gamma-Ray Spectrometry system was used for soil samples analysis. All measurements were performed with a Board Energy Germanium (BEGe) detector . The detector has 1.55 keV energy resolution (FWHM) for 1332 keV gamma line of ^{60}Co, 19.2% efficiency, relative to a 3'' x 3'' NaI(Tl) and covers the energy range of 5 keV to 3 MeV.

The detector is surrounding by a graded- Z shield consisting of low carbon steel, lead, tin, and copper with a thickness of 0.1, 2, 0.05, and 0.05 inch, respectively, which reduce the amount of background gamma radiation reaching the detector.

All samples were individually measured and analyzed using Genie 2000 software. The counting time for each sample was 19 h. (**FIG**. **3** shown the measured spectrum of sample 4). The energy calibration was performed using ^{226}Ra at 11 energy points (186.21, 295.22, 351.93, 609.31, 785.96, 934.06, 1120.29, 1238.11, 1377.67, 1764.49, and 2204.21 keV which best covers the energy range of interest.

The background spectrum was acquired for the empty bottle under the same measurement conditions. An area correction was performed by subtracting the background spectrum from the spectrum of each sample using Genie 2000 software to ensure the gamma peaks for the corresponding radionuclides are correct.

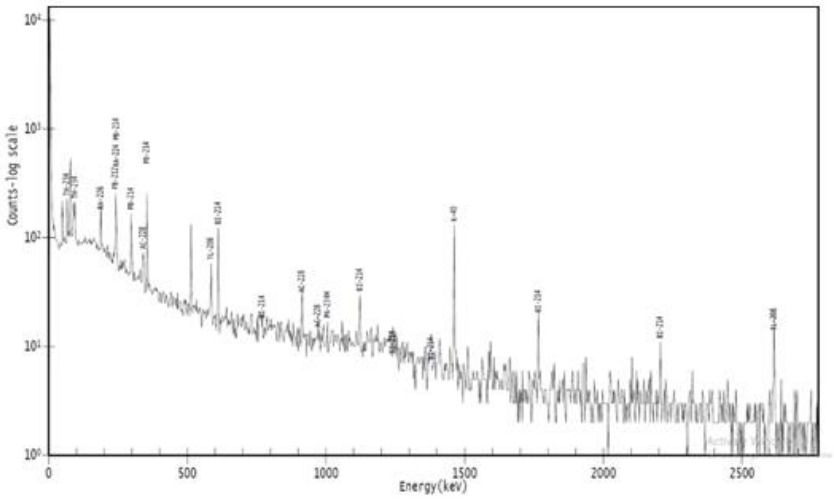

FIG. 3. **Gamma-ray spectrum from sample 4.**

The activity concentration of ^{238}U is measured through its stable progeny ^{226}Ra, which can confirm and represent the presence of ^{238}U in analyzed samples [7-12]. Since when in equilibrium, ^{226}Ra and its progenies produce 98.5% of the radiological effects from the uranium series. Thus, the contribution of ^{238}U itself and the precursors of ^{226}Ra are usually ignored, [11] so it is usually referred to radium instead of uranium.

The ^{238}U was determined by its progenies, ^{214}Pb with 351 keV (with emission probability of 37.6%) and ^{214}Bi with 609.31 keV (with emission probability of 46.1%). ^{232}Th activity concentration was detected by the energy peaks for ^{228}Ac

at 911.2 keV (with emission probability of 25.8%), ^{212}Pb at 238.63 keV (with emission probability of 43.3%), and ^{208}Tl at 583.19 keV (with emission probability of 84.5%). While the specific activity for ^{40}K was achieved directly through the photopeak of 1460.83 keV (with emission probability of 10.67%).

Measures of Radiological Impact

Activity and uncertainty calculation

The calculated of activity concentration was determined using the equation published by the International organization for Standardization (ISO) [13]:

$$A = \frac{n_{N,E}}{Y * \epsilon_E * m * t}, [Bq/kg] \quad (1)$$

Where $n_{N,E}$ is the total detected count under a gamma-peak, t is the total acquisition time (sec), ϵ_E is the detector efficiency, m is the sample mass in (kg), and Y is the emission probability (γ%), which represents the ratio gamma per disintegration.

The uncertainty was calculated for each soil sample, via the equation:

$$A_{Unc} = \pm \sqrt{\frac{1}{[\epsilon_E * Y * m * t]^2} * \sigma^2{}_{n_{N,E}} + \left[\frac{-n_{N,E}}{\epsilon_E^2 * m * Y * t}\right]^2 * \sigma^2{}_{\epsilon,E} + \left[\frac{-n_{N,E}}{m^2 * \epsilon_E * Y * t}\right]^2 * \sigma^2{}_m + \left[\frac{-n_{N,E}}{Y^2 * m * \epsilon_E * t}\right]^2 * \sigma^2{}_Y} \quad (2)$$

Where $A_{Unc}$is the uncertainty activity per unit mass, and σ is the standard uncertainty. The average uncertainty for ^{40}K, ^{232}Th and ^{238}U were also calculated for each region by the following equation and reported in **TABLE 1**.

$$Avg_{Unc} = \pm \sqrt{\frac{A_{Unc_1}{}^2 + A_{Unc_2}{}^2 + A_{Unc_3}{}^2 + A_{Unc_4}{}^2 + A_{Unc_5}{}^2}{5}} \quad (3)$$

Absorbed dose rates

Based on UNSCEAR 2000, 80% of the dose rates at ground level were directly from ionizing radiation that occurred naturally from radioactive materials such as ^{232}Th, ^{238}U series and ^{40}K [7]. The absorbed dose rate at 1m above the ground level calculated using the conversion factor of 0.462 nGyh^{-1}/Bq.kg^{-1} for ^{226}Ra, 0.604 nGyh^{-1}/Bq.kg^{-1} for ^{232}Th, and 0.0417 nGyh^{-1}/Bq.kg^{-1} for ^{40}K [14].

$$D_{out} = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (4)$$

Where D represent the absorbed dose rate (in nGyh^{-1}), while *A* represents the average concentration for ^{40}K, ^{232}Th and ^{226}Ra (in Bq.kg^{-1}), taking into consideration that all the decay product for ^{226}Ra and ^{232}Th assumed to be in secular equilibrium with their precursors [15].

Effective absorbed dose rates

Effective Absorbed Dose rates are an annual representation of Absorbed Dose rates.

With the assumption that the average person spends 20% of annual time outdoors [13], E_{out} is calculated as:

$$E_{out} = 0.2 * D_{out}(nGy * h^{-1}) * 8760(h) * 0.7\ (Sv * Gy^{-1})\ (5)$$

Where 0.2 accounts for the assumption made, and 0.7 is a conversion factor from Gray to Sieverts.

Hazard indices

The external hazard index defined as:

$$\mathrm{H_{ex}} = \frac{\mathrm{A_{Ra}}}{370} + \frac{\mathrm{A_{Th}}}{259} + \frac{\mathrm{A_K}}{4810} \leq 1\ (6)$$

Where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (in $\mathrm{Bq.kg^{-1}}$), the equation derived from Radium equivalent activity ($\mathrm{R_{eq}}$) expression. $\mathrm{H_{ex}}$ represent the maximum value equal to unity which corresponds to the upper limit of radium equivalent activity being 370 $\mathrm{Bq.kg^{-1}}$. The value of $\mathrm{H_{ex}}$ shouldn't exceed unity to reflect insignificant hazard levels [16,17].

Gamma index (Iɣ)

As proposed by the European Commission [18], additional external gamma-radiation from superficial material may be represented by the Gamma Index:

$$I_\gamma = \frac{A_{Ra}}{300\ Bq.kg^{-1}} + \frac{A_{Th}}{200\ Bq.kg^{-1}} + \frac{A_K}{3000\ Bq.kg^{-1}}\ (7)$$

The Gamma Index reflects the feasibility of using soil in building materials. Values of Iɣ that are greater than 1, imply that using soil for building materials should be avoided.

Radium equivalent activity (Raeq)

$\mathrm{Ra_{eq}}$ simplifies the comparison of samples containing different NORM concentrations [19]. It is made with the assumption that the coefficients of $\mathrm{A_{Th}}$ and $\mathrm{A_K}$ would emit equal gamma-dose rates to $\mathrm{A_{Ra}}$. $\mathrm{Ra_{eq}}$ is calculated as:

$$Ra_{eq} = A_{Ra} + \frac{10}{7}A_{Th} + \frac{10}{130}A_K \leq 370\ (8)$$

Results and Discussion

The activity concentrations of 238U, 232Th, and 40K were calculated by using the measured spectra of each composite soil sample, **FIG.4** presents a chart, showing NORM activity concentrations for each sample. Every five samples represent a region (samples 1 through 5 represent region 1, samples 6 through 10 for region 2, and so on). From this figure, the average NORM concentrations per region were calculated and listed in **TABLE 1**. The concentrations ranged from 6.27 ± 0.28 to

15.89 ± 0.47 for 238U, from 0.84 ± 0.11 to 6.10 ± 0.27 for 232Th, and from 29.4 ± 2.82 to 200.49 ± 8.91 for 40K. In all of the measured samples, the dominant activity concentration was that of 40K, and this is a common occurrence in most of the geological materials on Earth. Furthermore, all activity concentrations were far less of the World's Average as reported by UNSCEAR-2000 (35 for 238U, 30 for 232Th, and 400 for 40K) [13].

The outdoor Absorbed Dose rates in the air were calculated from the concentrations of 238U, 232Th, and 40K using equation (4). Its values ranged from 4.63 to 19.61 nGy/h. Proportional to NORM concentrations, 40K's contribution to dose is the highest, followed by 238U and then 232Th. According to UNSCEAR 2000 report [13], the world's average dose rate is 84 nGy/h, out of which 54.76 nGy/h comes from natural terrestrial radiation (Equivalent to 0.48 mSv) [20]. Making the highest Dout measured (in region 3) about 25% of the world's average. Moreover, the indoor Absorbed Dose rates spanned from 9.07 to 36.96, with the high-end value less than the world's average of 59.

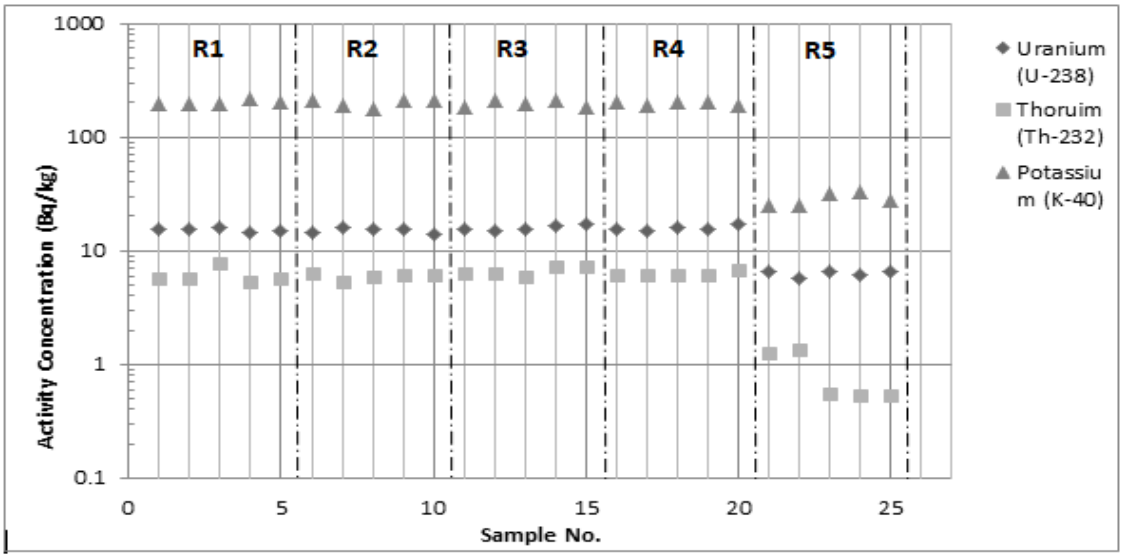

FIG.4. **Activity concentration of 238U, 232Th, and 40K in soil samples.**

TABLE 1. **Average activity concentrations (Bq/kg), the absorbed dose rate (nGy/h) and external radiation hazard index (Hex).**

Region	Avg Portable Gamma reading (nSv/h)	Average activity concentration Bq/kg			Dout (nGy/h)	Eout (mSv/y)	Hex
		238U	232Th	40K			
R1	71.5	15.23 ± 0.47	6.10 ± 0.27	200.49 ± 8.91	19.08	0.0234	0.106
R2	76	14.98 ± 0.46	5.97 ± 0.26	197.93 ± 8.75	18.78	0.023	0.105
R3	85	15.89 ± 0.49	6.59 ± 0.28	197.64 ± 8.76	19.56	0.024	0.109
R4	74.83	15.63 ± 0.48	6.22 ± 0.45	196.59 ± 8.75	19.18	0.0235	0.107
R5	48.17	6.27 ± 0.28	0.84 ± 0.11	29.4 ± 2.82	4.63	0.0057	0.026

Outdoor Annual Effective dose rates had a trough value of 0.0057 and a peak one of 0.0234, with the highest being less than the world's average value of 0.07. The External Hazard Index was calculated from NORM concentrations by utilizing equation (6). Its results ranged between 0.047 and 0.109. The higher-end value is about one-tenth of the safety limit of 1, indicating that the effect of radiation hazard in Sharjah is negligible [17,18].

From **FIG. 5** below, Ra_{eq} ranged between 9.73 to a maximum of 40.51 in region 3. The highest value is about ten times smaller than the world's average of 370 Bq/kg [13].

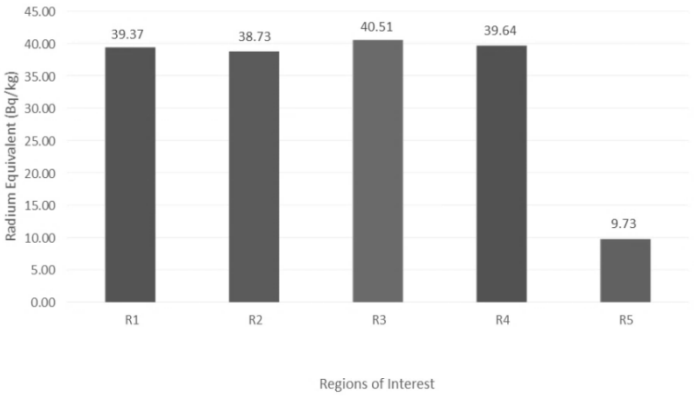

FIG. 5. **Radium Equivalent Activity per region.**

Due to having the same type of sand, regions 1 through 4 had almost identical NORM concentrations. **FIG.6** shows the average relative contributions of ^{238}U, ^{232}Th, and ^{40}K in these regions. 90.15% of radioactivity is solely produced by ^{40}K, followed by 7.02% from ^{238}U, and the remaining 2.83% were from ^{232}Th.

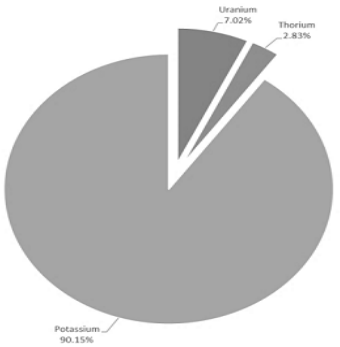

FIG. 6. **NORM relative contribution to radioactivity (Regions 1 through 4).**

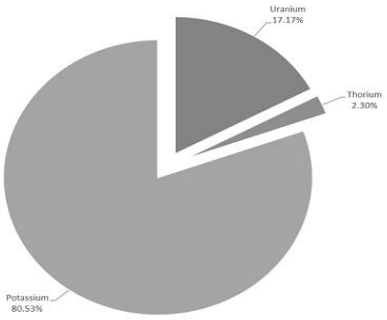

FIG. 7. **NORM relative contribution to radioactivity (Regions 5).**

Region 5 (on the coast of Sharjah) features a different type of sand, where NORM activity ratios are slightly different. From **FIG. 7**, 80.53% of radioactivity is being produced by ^{40}K, followed by 17.17% from ^{238}U, and finally 2.30% were from ^{232}Th. When compared to regions 1-4, region 5 offers higher ^{238}U presence and less ^{40}K. ^{232}Th's presence is slightly

less here (by ~0.5%) but is relatively the same.

Origins of Sand and Confidence in Measurement

FIG. 8 presents a geological map of the United Arab Emirates where the city of interest, Sharjah, is encircled in red. According to the map, the entirety of Sharjah is covered with 'Recent Deposits'. Since this study focuses on the sampling of surface soil rather than the fallout technique (where the latter requires depth-dependent sample collection), the mobility of sand particles becomes of concern.

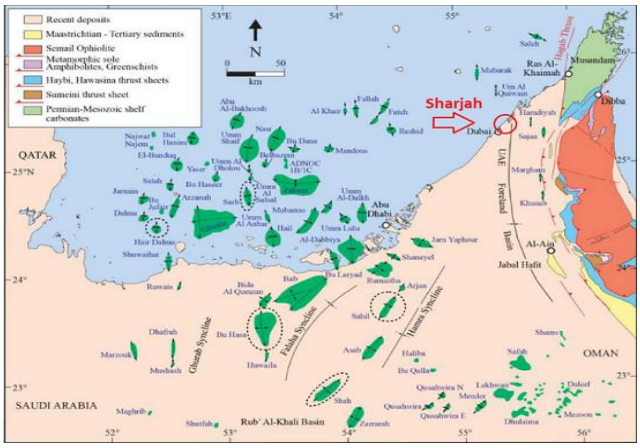

FIG. 8. **Surface geology map of the United Arab Emirates [22].**

In regions of the world where wind flows at sufficient velocities, it is possible for the surface soil to migrate, inducing a false representation of the measured area. Hence, annual wind statistics from a station based on Sharjah Airport are ideal to investigate the originality of measured samples.

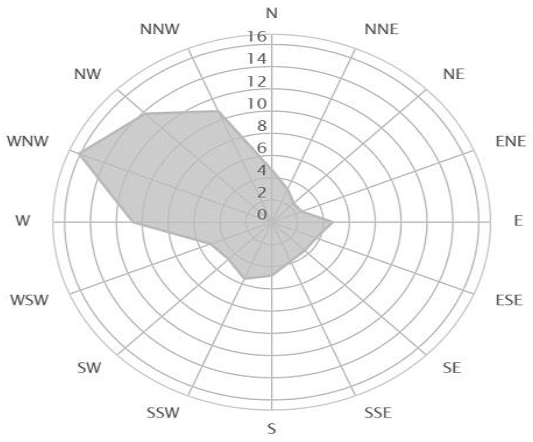

FIG. 9. **Wind rose,obtained from a station established on Sharjah's International Airport (Courtesy of Windfinder).**

The wind rose in **FIG. 9,** a plot that describes the percentage of winds and their direction in a given area, suggests that most winds are received from the North-West on an annual basis. However, a maximum of about five percent of the total annual flow of winds does approach the city from the opposite direction (South-East). If present, any and all surface creep (rolling-movement of sand particles along terrain due to winds) from the South-East direction would be reversed by the dominant winds from the North-West direction.

TABLE 2. **Annual summary of wind over Sharjah's International Airport (Windfinder).**

Month	**Jan 01**	**Feb 02**	**Mar 04**	**Apr 05**	**May 06**	**Jun 06**	**Jul 07**	**Aug 08**	**Sep 09**	**Oct 10**	**Nov 11**	**Dec 12**	**Year 1-12**
Wind Probability (%)	18	29	29	31	41	32	32	34	25	22	15	14	26
Wind Speed (m/s)	4	4	5	5	5	5	5	5	4	4	4	4	4
Dominant Direction	100°	92°	91°	103°	107°	112°	124°	123°	126°	114°	113°	111°	109°

TABLE 2 is an annual summary that explains the behavior of winds at the city of Sharjah. Data suggests that the highest wind speed recorded throughout the year was five meters per second, with a yearly average of four meters per second. In order for surface creep to occur, winds must flow with a velocity of at least 16 km/h. This is the minimum wind velocity needed to start moving a 0.1 mm in diameter grain of sand along a given surface, at a height of 30.5 cm [22]. This velocity is equivalent to 4.44 m/s, which is slightly higher than the annual average recorded at Sharjah's International Airport, at the center of the 5 sampling regions. Moreover, the practical wind velocity threshold that considers all different sizes of movable sand is rated to be 21 km/h (5.833 m/s), which is well over the maximum recorded wind velocity on Sharjah. With that said, it is safe to note that soil creeps in the city of Sharjah are negligible to none, meaning that surface soil sampled from Sharjah is unique to the city and should hardly be present in the neighboring countries.

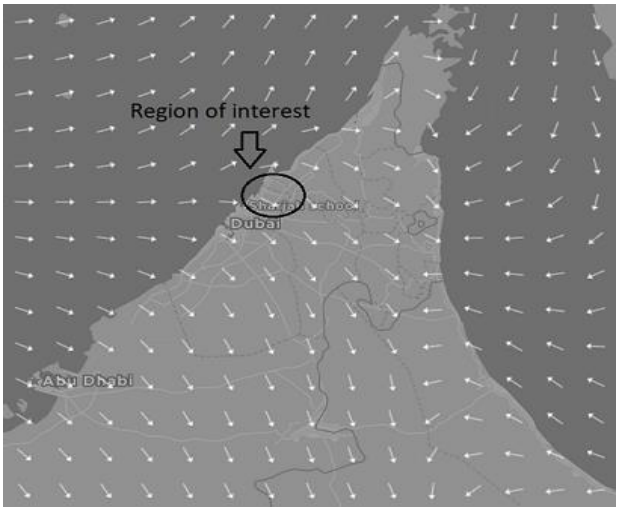

FIG. 10. **Wind vectors at the city of Sharjah and its surroundings (Windfinder).**

FIG. 10 above shows the flow direction of winds on the area of study, which for the city of Sharjah, remains relatively constant throughout the year. Once more, the dominant direction is South-East, meaning that the city of Sharjah receives most of its winds from the Arabian Gulf. Since **TABLE 2** suggests sub-creep wind velocities, it is inferred that there are virtually no sand particles received from that direction. Finally, since the exchange of sand particles (creep) to and from Sharjah city is almost inexistent, we assure that the measured samples for NORM concentrations represent Sharjah and Sharjah city only.

Comparison of Results

To promote verification, it is imperative to compare our results with those of studies conducted within the country. One study was selected for direct comparison. Their objective was to perform a baseline study in order to contribute towards a baseline radiation mapping for the entirety of the United Arab Emirates. The results of this study have been placed side by side with ours in **TABLE 3**.

TABLE 3. **Comparison of NORM concentrations in the UAE.**

Sample type	**^{226}Ra Concentration (Bq/kg)**	**^{232}Th Concentration (Bq/kg)**	**^{40}K Concentration (Bq/kg)**	**References**
Sand Soil	6.27-15.23	0.84-6.59	29.40-200.49	Present study
Agriculture Soil	10-22.1	2.2-11	167.4-510	Ajaj et al. (2018) [23]
World Average	35 17-60	30 11-64	400 140-850	UNSCEAR report (2000) [13]

The comparison implies a consistent trend of NORM activities throughout the United Arab Emirates. Thorium concentrations are the least, followed by Uranium and Potassium. Variations observed in the upper and lower bounds of NORM concentrations are most likely due to the wide range at which samples were collected.

Conclusion

The present work is amongst the first of its kind to focus solely on Sharjah city. It provides data on the activity concentration of radionuclides of the uranium, thorium series, and potassium in soil samples of different regions in Sharjah. Low-background gamma-ray spectroscopy was used at the Applied Radiation Measurement Laboratory of the University of Sharjah, to assess the quantity of uranium, thorium, and potassium in soil samples. Plus, their contribution to the annual effective dose equivalent to the population and external hazard index (Hex) was also measured. A Gamma-ray spectrometry system coupled with a broad energy germanium detector was used to measure the presence of natural radionuclides in soil samples. The measured activity concentrations for 238U, 232Th, and 40K were found to be ranging between 6.27 ± 0.28 to

15.23 ± 0.47, 0.84 ± 0.11 to 6.10 ± 0.27, and 29.4 ± 2.82 to 200.49 ± 8.91 Bq/kg respectively. The corresponding dose rates, effective dose rates, hazard indices and excess lifetime cancer risks from these concentrations were measured to be far below the world's average values. Furthermore, wind statistics ensure that soil creeps within Sharjah are negligible to none. With this information, it is safe to conclude that the terrestrial radiation levels from the sands of Sharjah are natural.

Acknowledgement

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