

DOI: <https://doi.org/10.24297/jap.v19i.8991>

Nuclear Power Plants Pre-operational Radiological Monitoring Mapping for the Coastal Borders and Islands of the United Arab Emirates (UAE)

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Abstract

In the light of the peaceful nuclear power plants (NPPs) project of the United Arab Emirates (UAE), the operation license has been issued and the first unit is being in commercial operation. This work deals mainly with radiological surveillance of the coastal boarder and some Islands of UAE as a baseline reference natural and artificial radioactivity mapping. Ultra-sensitive hyper pure Germanium (HpGe) detector was used to carry out the non-destructive gamma measurements. The area of study was divided into; Abu Dhabi region, northern emirates and islands. About 85 soils, shore sediment and water samples were collected based on the scientific sampling mechanism. The samples were analyzed for X-ray diffraction mineralogy (XRD). The radioactivity in Bq/kg of the natural ^{238}U (^{226}Ra), ^{232}Th and ^{40}K were calculated for all the collected samples. The artificial ^{137}Cs was also observed in very low activity. The hazard indices were also calculated and found to be less than the recommended international and regional limits. The correlations between the measured radioisotopes were also depicted. The results were compared, presented and given in 3D histograms.

Keywords: NPPs of UAE and sites, γ -spectrometer, Natural-artificial radioactivity, Hazard indices calculations.

1. Introduction

The United Arab Emirates is the first state in the Middle East to operate nuclear power plants for electricity production. Preoperational monitoring mapping is a vital target to be carried out as pre-operational and post-operational safety measures. This natural background forms a baseline which the levels and impacts of other sources of radioactivity in the environment are subjected to evaluation. Naturally occurring radioactive materials (NORMs) from the ^{232}Th and ^{238}U series are present in the earth's crust (1). According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and other sources, about 87% of the radiation received by mankind is due to natural radiation sources (2). Natural radioactivity has been determined in working environment (3,4,5). Environmental analysis is one of the vital instruments to assess the impact of man-made activities on the environment, and the methods of determine radioactivity levels are well documented. The UAEs started to commercially operate the first nuclear power plant (NPPs); the operation license for the first reactor has been awarded in Feb. 2020., There are very limited studies on the evaluation and pre-operational monitoring of natural and man-made radioactivity levels in the country (UAE). Establishing a baseline reference radiological map before the full commercial operation of the UAE's nuclear power plants is the main target and objective of this paper including the hazard indices calculations to evaluate any potential environmental threat.

2. Experimental work

2.1. Site description and characteristics

The United Arab Emirates (UAE) is located in the Middle East, in the south-eastern part of the Arabian Peninsula. The United Arab Emirates has a 644-kilometer-long coast at the southern Arab Gulf, where the 7 UA Emirates of Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al-Quwain and Ras Al-Khaimah are located, while the 90-kilometer-long coast of the Emirate of Fujairah is located at the Gulf of Oman. The area of the country is 83,600 square kilometers, with the desert dominating most of this area with many popular oases. Most of the country's coast is dominated by sand except for the northern area at Ras Al-Khaimah which constitutes the Hajer mountain cape. The country has hundreds of islands within the Gulf, of which 200 are in the Emirate of Abu Dhabi, importantly Sir BaniYas which has evolved into an oasis and a conservation area for rare birds and animals. Other



important islands include Das island, Abu Al-Abyadh island, Abu-Mousa island and Sir Bu Nair at Sharjah, Greater Tunb, Lesser Tunb and Al-Hamra at Ras Al-Khaimah, and Al-Jazira Al-Syniyah at Umm Al-Quwain [6].

2.2. Sampling program and locations

This surveillance monitoring covers the coastal border of UAE as well as some marine islands. The systematic sampling method was used for sampling location selection. The samples numbers and the interval between them were selected based on the study area, analysis and measurement capacity, evidence of variation (like soil type change or human activity) and finally cost benefit analysis. A total number of 85 sampling stations were selected for the 79 collected samples. The detailed sampling sites, codes and samples types are presented in figure 1.

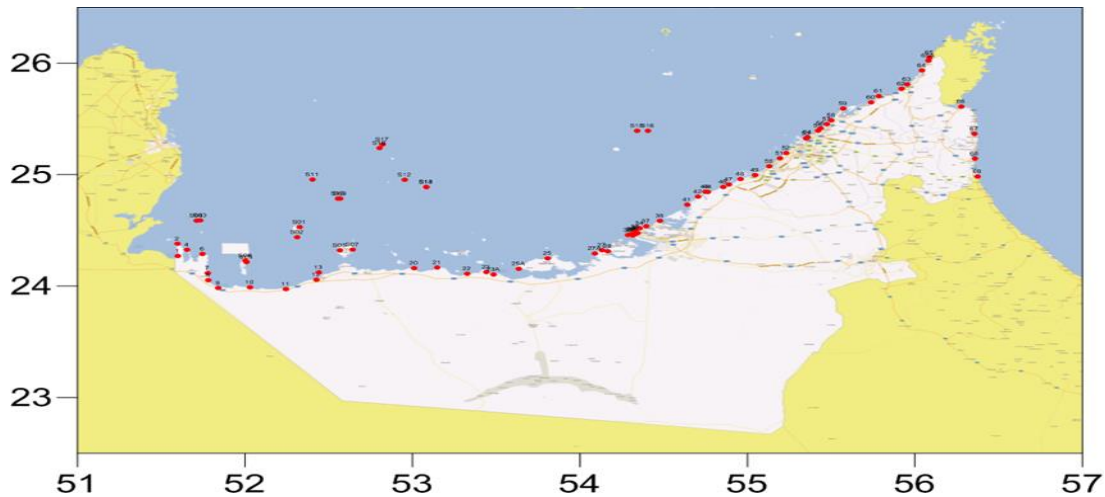


Figure 1 Map of UAE Showing the Sampling Locations of the Studied Areas

2.3. Sample preparation:

After sampling, the shore sediment and soil samples were prepared for gamma analysis according to the following procedure:

- i. The sample was separated from pebbles and plant roots, weighed and dried for 10 hrs. in an oven at a temperature of 110 °C, re-weighed until constant weight achieved to determine the water content.
- ii. The sample was crushed, homogenized and finally sieved through a 2 mm mesh sieve.

The sieved samples were weighed, packed in Marinelli-type beakers and carefully sealed and stored for 4 weeks to reach secular equilibrium between ^{226}Ra and its decay products [7,8]. The XRD analysis was then carried out for some samples. The major minerals of soil and shore sediments are quartz and calcite.

The Gulf-water samples were collected from the surface beyond the tidal area, filtered through 0.45 μ membrane filter, acidified with 11M HCl at the rate of 10 ml per litre of sample immediately after filtration to avoid the adsorption of radionuclides on the walls of the container [7,8] transferred to polyethylene bottles and transferred to laboratory.

2.4. Gamma spectrometry efficiency and activity analysis:

The gamma ray spectrometers were equipped with hyper pure germanium detector, which consists of: A hyper pure germanium coaxial detector of a vertical configuration (Canberra, Model GC4020) with a relative photo peak efficiency of 40% at the 1332.5keV transition line of ^{60}Co . The detector is mounted on a 30 litres liquid nitrogen. The preamplifier is coupled to the detector and connected to the germanium crystal, and the components are kept at liquid nitrogen temperature (77 °K) to reduce detector noises which are caused by the leakage current generated by the charge carriers at room. The energy calibration and efficiency calculation were then carried out. The generated efficiency curve is given in figure.2.

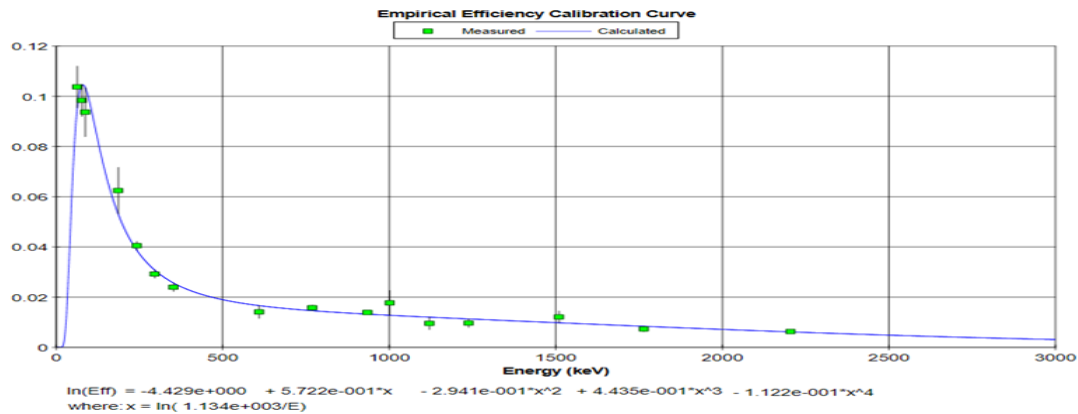


Figure 2: Relative Efficiency of HPGe Detector using ²²⁶Ra source and its Daughters

2.5. Quality assurance and control (QA/QC) program

Quality control program was precisely applied for confident radioactivity measurements, calculations and results. Replicate samples usually consist of two or more aliquots of homogeneous solid and liquid samples. Individual samples that are measured by non-destructive techniques, such as (γ-ray spectrometry, may be measured more than once to obtain replication of the data. The QAQC system applied in this work includes analysis of reference standard IAEA materials such as; RGU-1 and RTh-1. This is in addition to documentation from sampling to activity calculations. New correlation for nuclear fields was recently given for activity calculations (9)

2.6. Hazard indices assessment

The major hazard indices were calculated using the following equations to evaluate the potential risk due to the measured radioactivity (Ra equivalent, absorbed dose rate, external hazard index, gamma index and alpha index respectively) (2,10).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \tag{1}$$

Where: C_{Ra} , C_{Th} and C_K are the specific activities of ²²⁶Ra, ²³²Th and ⁴⁰K in Bq/kg, and this formula is based on the estimation that 1 Bq/kg of ²²⁶Ra, 0.7 Bq/kg of ²³²Th or 13.0 Bq/kg of ⁴⁰K produce the same gamma dose rate. The Ra_{eq} limit should be less than 370 Bq/kg (2,5).

$$D = 0.462 C_U + 0.604 C_{Th} + 0.0417 C_K \tag{2}$$

Where: D is the absorbed dose in nGy/hr., R_K , R_U , R_{Th} are the conversion factors, expressed in nGy/hr, per Bq/kg (UNSCEAR, 2008). The C_K , C_U , C_{Th} are the activity concentration of ⁴⁰K, ²³⁸U(²²⁶Ra) series and ²³²Th series respectively, expressed in Bq/kg dry weight soil.

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \tag{3}$$

Where: A_{Ra} , A_{Th} , and A_K are the mean activities of ²²⁶Ra, ²³²Th, and ⁴⁰K in Bq/kg. The safe value of this index must be less than 1 (2).

$$I_\gamma = A_{Ra}/300 + A_{Th}/200 + A_K/3000 \leq 1 \tag{4}$$

Where A_{Ra} , A_{Th} and A_K are the specific activities of ²²⁶Ra, ²³²Th and ⁴⁰K, respectively, The value of $I_\gamma \leq 0.5$ corresponds to a dose rate criterion of 0.3 mSv/y, whereas $0.5 \leq I_\gamma$ corresponds to a criterion of 1 mSv/y . Materials with $I_\gamma > 1.0$ should be avoided in building construction. They will deliver an effective dose rate higher than 1 mSv/y to the occupants of such buildings.

$$I_\alpha = A_{Ra}/200 \tag{5}$$

Where, A_{Ra} is the specific activity of ²²⁶Ra. The safe use of materials in building construction requires I_α (alpha index) to be less than 1. This limit corresponds to the design action level for the ²²²Rn concentration of 200 Bq/m³ on an annual average basis for future buildings.

3. Results and discussion.

The studied three regions (Abu Dhabi, Dubai & Northern emirates and Islands) results of analyses and calculations were compared and given in the following tables and 3D figures. The comparison was carried out for the observed radionuclides in soil, shore sediments and water samples. The correlation and its coefficients were also given and depicted.

3.1. Average Activity of soil for the three studied regions

The comparison of measured average activity concentrations for ²²⁶Ra, ²³²Th, ⁴⁰K, ¹³⁷Cs (table 1 and figures 3-5) and the world average for soil samples (2). The variation in the measured specific activities may be related to the differences in major minerals of soil and shore sediments; quartz and calcite. The grain size fractionation shows that silt and sand are the main constituents of the analyzed samples.

Table 1: The average activity of soil for the three studied regions with the world values

Sample Code	²²⁶ Ra (Bq/kg)			²³² Th (Bq/kg)			⁴⁰ K (Bq/kg)			¹³⁷ Cs (Bq/kg)		
Abu Dhabi												
Minimum	2.79	±	0.13	0.57	±	0.02	16.12	±	0.81	0.04	±	0.01
Maximum	55.05	±	2.75	18.47	±	0.92	531.08	±	26.5	3.77	±	0.18
Average	16.68			4.09			113.74			0.78		
Dubai and Northern Emirates												
Minimum	1.8	±	0.09	0.68	±	0.03	5.04	±	0.25	0.08	±	0.01
Maximum	23.09	±	1.15	9.70	±	0.48	139.94	±	7.00	0.8	±	0.04
Average	9.11			2.72			54.58			0.23		
Islands												
Minimum	1.24	±	0.16	0.61	±	0.03	4.85	±	0.24	0.05	±	0.01
Maximum	44.43	±	2.22	16.44	±	0.82	488.69	±	24.4	7.00	±	0.35
Average	16.83			3.93			123.08			1.20		
World Average	35			30			400			---		

The results are also depicted and compared as given in the following figures

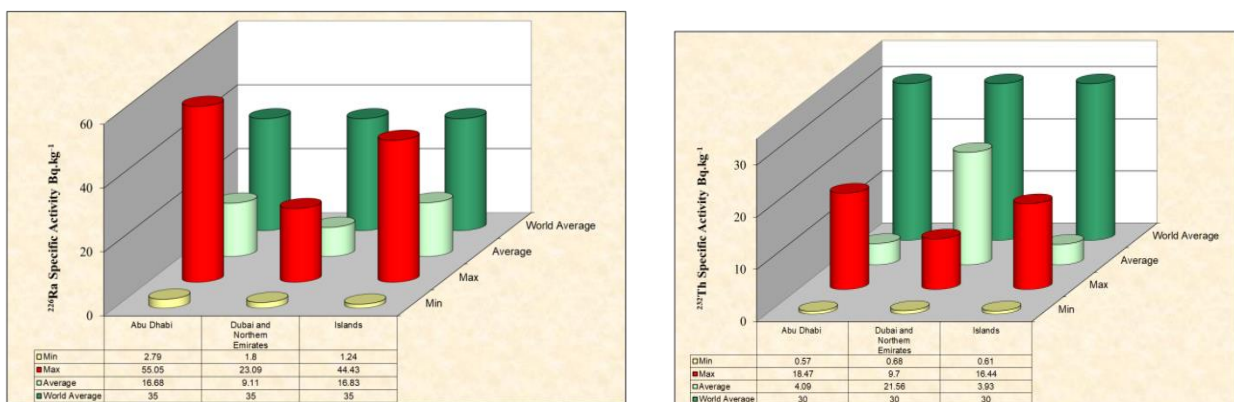


Figure 3 and 4: The average ²²⁶Ra and ²³²Th activity of soil for the three studied regions

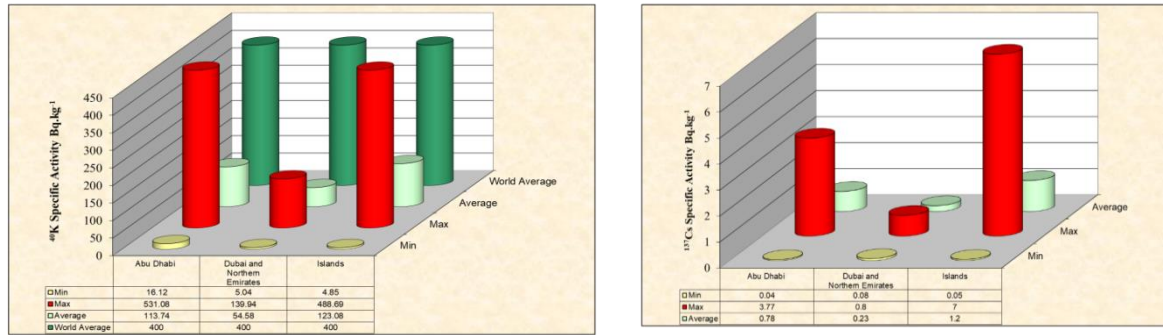


Figure 5 and 6: The average ⁴⁰K and ¹³⁷Cs activity of soil for the three studied regions

The correlation between ²²⁶Ra and ²³²Th in soil of the 3 regions was carried out and given in fig.7. It can be observed that a low correlation coefficient ($R^2 = 0.3691$) was found.

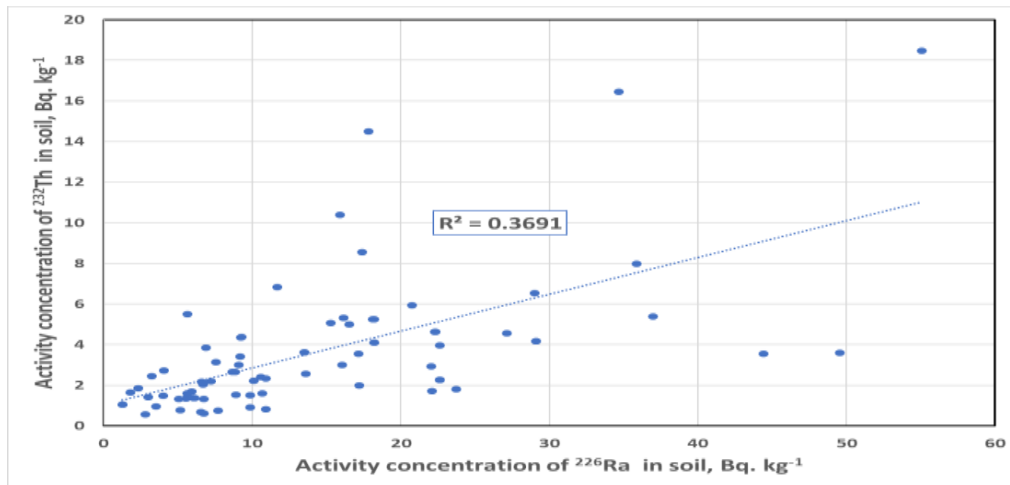


Figure 7: The correlation of ²³²Th and ²²⁶Ra activity of soil for the three regions

3.2. Average activity of shore sediment for the three studied regions

The comparison of measured average activity concentrations observed for ²²⁶Ra, ²³²Th, ⁴⁰K, and ¹³⁷Cs in shore sediment (table 2 and figures 8-11) and the world average in shore sediment samples (2). These values are fairly low compared to those in coastal marine sediments reported in literature. The slight variation of radionuclides activities may be attributed to the sediment components and textural properties.

Table 2: The average activity of shore sediment for the three studied regions

Sample Code	²²⁶ Ra (Bq/kg)			²³² Th (Bq/kg)			⁴⁰ K (Bq/kg)			¹³⁷ Cs (Bq/kg)		
Abu Dhabi												
Minimum	1.15	±	0.05	0.74	±	0.03	0.58	±	0.02	0.02	±	0.01
Maximum	25.5	±	1.27	10.3	±	0.51	528.76	±	26.43	3.26	±	0.16
Average	10.6			3.35			121.75			0.45		
Dubai and Northern Emirates												
Minimum	0.63	±	0.03	0.78	±	0.03	9.04	±	0.45	0.03	±	0.001
Maximum	14.41	±	0.72	7.81	±	0.39	215.32	±	10.76	0.88	±	0.04
Average	6.29			2.41			61.48			0.26		

Sample Code	²²⁶ Ra (Bq/kg)		²³² Th (Bq/kg)		⁴⁰ K (Bq/kg)		¹³⁷ Cs (Bq/kg)	
Islands								
Minimum	1.71	± 0.08	0.46	± 0.02	14.33	± 0.72	0.07	± 0.003
Maximum	67.60	± 3.38	27.5	± 1.35	215.50	± 10.77	1.11	± 0.05
Average	13.24		3.55		76.72		0.33	
World Average	35		30		400		---	

The results are also depicted and shown in the following figures.

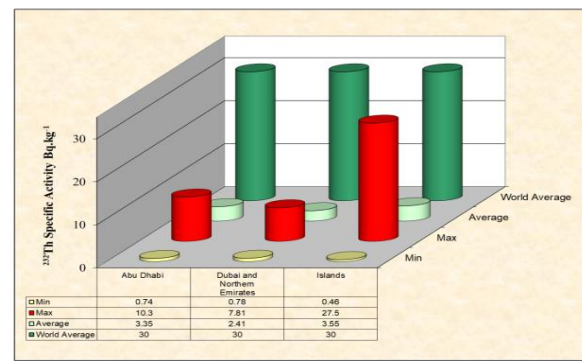
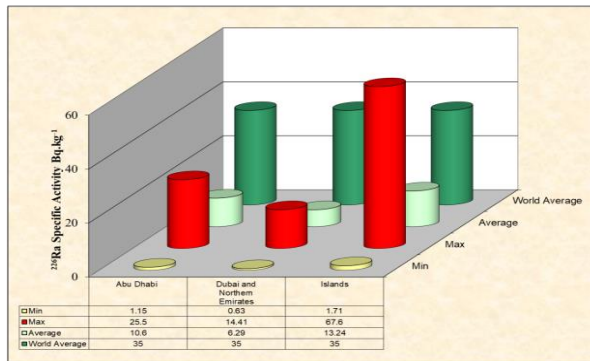


Figure 8 and 9: The activity of ²²⁶Ra and ²³²Th in the three studied regions

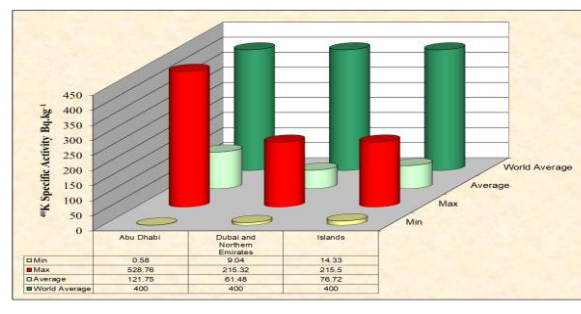
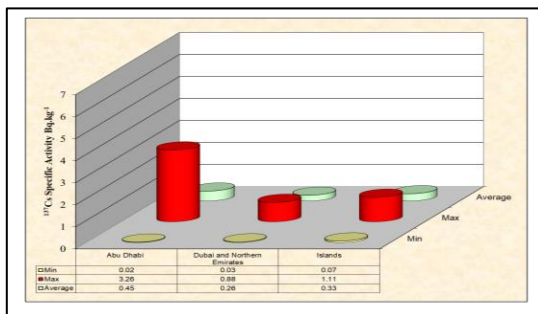


Figure 10 and 11: The activity of ¹³⁷Cs and ⁴⁰K in the three studied regions

The correlation between ²²⁶Ra and ²³²Th in shore sediment of the 3 regions was carried out and given in figure.12. It can be observed that a medium correlation coefficient ($R^2 = 0.6182$) was found.

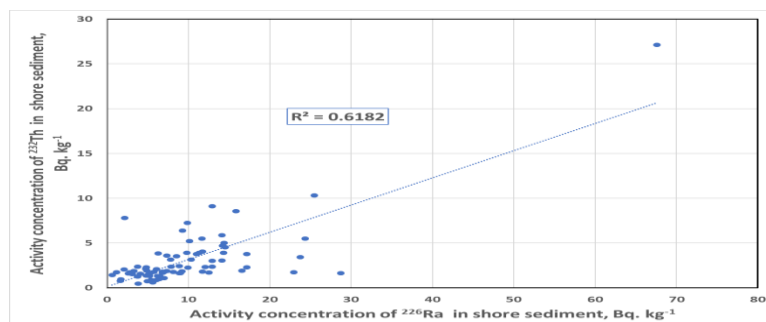


Figure 12: The correlation between ²²⁶Ra and ²³²Th activity of the three regions

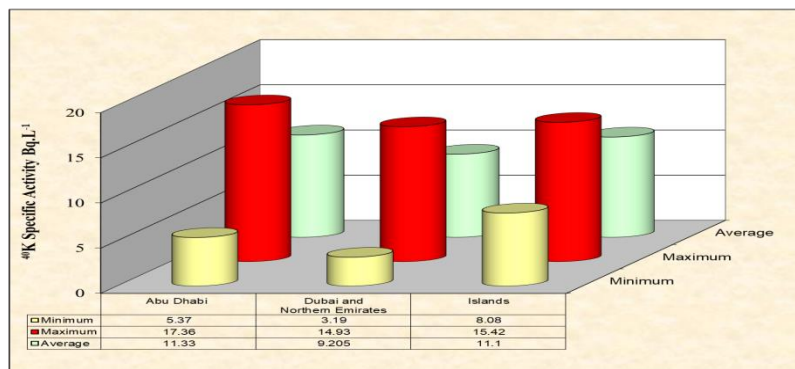
3.3. Average activity of Gulf water for the three Regions

The comparison of measured average activity concentrations for ⁴⁰K (table 3 and figures 13) and the average value in the Gulf water samples of the three studied regions (2).

Table 3: The ^{40}K activity in the water of the three studied regions

Activity Bq L ⁻¹	Abu Dhabi	Dubai and Northern Emirates	Islands
Minimum	5.37 ± 0.26	3.19 ± 0.15	8.08 ± 0.40
Maximum	17.36 ± 0.86	14.93 ± 0.72	15.42 ± 0.77
Average	11.33	9.205	11.1

The presented results can be shown in the following figure (Fig.13).

Figure 13: The activity of ^{40}K in the three studied regions

3.4. The calculated Hazard indices values:

The calculated radium equivalent (R_{eq}) activities for soils and sediments were determined and their mean values were well below the defined limit of 370 Bq/kg as stated in UNSCEAR 2008 (2). The absorbed dose rate from external gamma radiation from soils and sediments was also estimated and the average values were far below the international recommended limit of 79.0 nGy/hr (2). The annual effective dose from the soil and sediment samples was determined and found to have an average value of 0.02 and 0.01 mSv/yr respectively, which are both far below the world average value of 0.09 mSv/yr. The mean values of the external and internal hazard indices were calculated; for soils and sediments, they are 0.07 and 0.06 respectively, which are far less than unity, and that keep the radiation hazard insignificant. The activity indices (gamma index – alpha index) were also calculated and their values were also found to be below the world limits (2) and other regional monitoring values (11,12,13).

4. Conclusion

The preoperational monitoring is a must for any nuclear power plants safe operation. The Surveillance and monitoring along the United Arab Emirates (UAE) coastal areas and some islands have been carried out to ensure that the radiation levels and doses received to the public are below the authorized national and international limits. The following major observations are concluded:

- Based on this work, the pre-operational natural and artificial monitoring mapping. for the NPPs site of the UAEs were carried out and available.
- The results obtained in this work cover a wide area along the United Arab Emirates (UAE) coastal line, and can be considered as a baseline radioactivity map for these regions that can be utilized as a preliminary pre-operational map before the full commercial operation of the first nuclear power plants (NPPs) and effluents control signals and monitor for post-operational mode.
- The average specific activity of the natural ^{226}Ra , ^{232}Th , ^{40}K and the artificial ^{137}Cs due to the global fall-out, in the soil samples were 14.5, 3.7, 98.2 and 0.7 Bq/kg respectively. These values were found to be lower

than those reported in soils from different countries and the international UNSCEAR levels (35, 30 and 400 Bq/kg for ^{226}Ra , ^{232}Th and ^{40}K respectively).

- The average specific activity of ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs in the sediment samples were 9.7, 3.2, 98.6 and 0.4 Bq/kg respectively.
- It is observed that ^{137}Cs is the only man-made anthropogenic isotope to be detected in the regions.
- Potassium-40 was the only natural radionuclide detected by gamma spectrometry in the sea (Gulf) water samples with a mean value of 10.6 Bq/L. This value was expected for the natural radioactivity in seawaters and oceans. This value does not impose any considered exposure for swimming and recreational activities along the coastal beaches of the UAE
- The calculated radium equivalent (R_{eq}), the absorbed dose rate from external gamma radiation, the annual effective dose, the mean values of the external and internal hazard indices, the activity indices (gamma index – alpha index) values due to soil and sediment were found to be below the world limits and they don't pose any radiological hazards.

Finally, it can be concluded that the results of this study is of great importance for emergency planning and the site monitoring before and after the plants (NPP) operation. The results can be considered as reference to control and evaluate the plant impact on the environment and public in the UAE.

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Biography

Ali Saeed Almeqbali is a researcher from the United Arab Emirates working in the field of radiation protection, he is a Ph.D. post-graduate student at Cardiff Metropolitan University, UK. He graduated from the UAE University with a bachelor's degree in chemistry and a master's degree in environmental science.

For about twenty years, Ali was working in the field of radiation protection in the UAE Military, where he was in charge of multiple projects related to chemical and radiation safety.

At the moment, Ali is managing a company that is specialized in providing training and equipment solutions in the field of CBRN.

