Cardiff Metropolitan University
Prifysgol Fetropolitan Caerdydd

Determination of Natural Radioactivity in the United Arab Emirates

By

Ali Saeed Rashed Almeqbali

School of Health Sciences

Cardiff Metropolitan University

2022

Determination of Natural Radioactivity in the United Arab Emirates

Ali Saeed Rashed Almeqbali

B.Sc. Science (Chemistry), M.Sc. in Environmental Science

Thesis submitted for the degree of Doctor of Philosophy

In Environmental Health at Cardiff Metropolitan University

School of Health Sciences

Supervisors

Prof. George Karani – Director of Study

Prof. Sayed Ali El-Mongy

2022

DEDICATION

I would like to dedicate my thesis to the founder of the United Arab Emirates (UAE), Sheikh Zayed bin Sultan Al Nahyan; May God have mercy on him, whose life and achievements inspired me to perform this research work.

Whilst being a great leader with deep vision, determination and strong faith, he devoted his life to serving people and taking care of to the environment. Environment safety and public health were essential values to Sheikh Zayed.

With the right guidance and hard work of his successors, we live in a safe and secured State.

The UAE has proceeded with plans to set up on its own an ambitious nuclear power programme as part of its clean energy strategy

With such plans in mind, radiation monitoring and surveillance are crucial to ensure environmental safety

And even though this thesis is a contribution to all efforts that were done for the environment safety and research, I believe that every small brick in the great wall of the UAE matters and this is what makes my country better place and worldwide destination.

AKNOWLEDGEMENTS

Foremost, I would like to express my sincere gratitude and appreciation to my supervisor Professor George Karani, the Director of Centre for Occupational & Environmental Public Health, for the opportunity to become a part of Cardiff Metropolitan University, for his continuous support, motivation, patience, and vast knowledge.

I also would like to thank Professor Sayed Ali El-Mongy for encouraging me to do this research and supporting me during all stages of this study, providing me his academic and technical experience and guidance.

I would like to thank the Team of Chemical Defence Command of the UAE Armed Forces (The Main Laboratory) for helping me with the most important and time-consuming part of my research: sample collections and measurements of the natural and artificial radioactivity. Without their help and affords, I cannot imagine completing the research part of my thesis.

Finally, I would like to extend my gratitude and appreciation to all my family members and friends as they were the source of my inspiration in this study.

ABSTRACT

Natural radioactivity is a common constituent of all environmental matrices: Geosphere, Hydrosphere and Biosphere. It was either primordially or cosmogenically produced. During their lifetime, human beings can be exposed to environmental radioactivity in several ways. Therefore, it is important to track the source and origin of the nuclear activities; either natural or other declared/undeclared activities (e.g., nuclear power plant operation).

United Arab Emirates has proven its determination to move forward with its nuclear policy commitments through several steps, the most important of which are the adoption of international instruments related to nuclear safety and security and the non-proliferation of nuclear weapons, as well as the adoption of the establishment of a legal and governmental framework within the state, and it shows its determination through continuous support for the development of the UAE Peaceful Nuclear Energy program.

In the framework of the ambitious peaceful nuclear program of the United Arab Emirates (UAE), this work was launched to draw a pre-operational baseline reference natural and artificial radioactivity image and map.

The International Atomic Energy Authority (IAEA) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) documents were considered the backbone of this work. A comprehensive regional and worldwide literature survey was summarised and presented in a separate chapter.

In the field, four wheeled drive vans, aircrafts and boats were used to reach the sites to be monitored. The area of study was divided into four major regions. Abu Dhabi Emirate, Dubai and Northern Emirates and Islands in the Arabian Gulf. 79 soil, sediment, and water samples were collected using the specific planned sampling mechanism.

An advanced γ-spectrometer; High Purity Germanium (HPGe) with its electronics and software, was used to identify and quantify radionuclides and their radioactivity. The system was energy and efficiency calibrated using standard ^{137}Cs, ^{60}Co and ^{226}Ra Check Sources.

For the collected samples, the chemical and physical properties were determined; mechanical and x-ray diffraction analysis were also carried out. The specific activities of natural ^{238}U, (^{226}Ra) were calculated and found in soil samples to be in the range (from 1.24 ± 0.16 to 55.05 ± 2.75 Bq/kg), in shore sediments samples to be in the range (from 0.63 ± 0.03 to 67.60 ± 3.38 Bq/kg). The specific activities of natural ^{232}Th were calculated and found in soil samples to be in the range (from 0.57 ± 0.02 to 16.44 ± 0.82 Bq/kg), in shore sediments samples to be in the range (from 0.46 ± 0.02 to 27.5 ± 1.35 Bq/kg). The specific

activities of natural ^{40}K were calculated and found in soil samples to be in the range (from 4.85 ± 0.24 to 531.08 ± 26.5 Bq/kg), in shore sediments samples to be in the range (from 0.58 ± 0.02 to 528.76 ± 26.43 Bq/kg), in Gulf water samples to be in the range (from 3.19 ± 0.15 to 17.36 ± 0.86 Bq/L)

The specific activities of anthropogenic fall-out ^{137}Cs were calculated and found in soil samples to be in the range (from 0.04 ± 0.01 to 7.00 ± 0.35 Bq/kg), in shore sediments samples to be in the range (from 0.02 ± 0.01 to 3.26 ± 0.16 Bq/kg). The hazard indices, radium equivalent, annual effective dose, external hazard index, γ- and α-index, were also estimated and evaluated.

The measured specific activities of ^{238}U (^{226}Ra), ^{232}Th, ^{40}K and ^{137}Cs are presented in figures and tables. The correlations and 3D figures with comparison with the mean worldwide values are also presented. It was clearly observed that the obtained activity and hazard indices are within the reference recommended values and limits.

Finally, the results of this thesis will also be used as a radiological and environmental safety signature for monitoring operation of the first peaceful nuclear power plant in the UAE.

PUBLICATIONS

During the course of my work and following the analysis of the experimental data a decision was made to publish my work in some reputable scientific journals. The first publication entitled **"Nuclear Power Plants Pre-operational Radiological Monitoring Mapping for the Coastal Boarders and Islands of the United Arab Emirates (UAE)"** was submitted and published in Journal of Advances in Physics Vol 19 (2021) ISSN: 2347-3487, https://doi.org/10.24297/jap.v19i.8991. I also have the intention to publish more work in other journals in time to come.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

($\varepsilon_{(E)}$) - Relative efficiency at energy

(µGy/h) - Microgray per year

(µSv/y) - Microsievert per year

(^{10}Be) - Beryllium 10

(^{115}In) - Indium 115

(^{133}Ba) - Barium 133

(^{137}Cs) - Caesium 137

(^{13}Cd) - Cadmium 13

(^{14}C) - Carbon 14

(^{210}Pb) - Lead 210

(^{210}Po) - Polonium 210

(^{222}Rn) - Radon 222

(^{226}Ra) - Radium 226

(^{22}Na) - Sodium 22

(^{232}Th) - Thorium 232

(^{238}U) - Uranium 238

(^{35}S) - Sulphur 35

(^{39}Cl) -Chlorine 39

(^{3}H) - Tritium, hydrogen

(^{40}K) -Potassium 40

(^{50}V) - Vanadium 50

(^{55}Fe) - Iron 55

(^{60}Co) - Cobalt 60

(Bq/Kg) - Becquerel per kilogram (Specific activity)

(Bq/l) - Becquerel per litre

(Bq/m3) - Becquerel per cubic meter

(CaCO3) - Calcium Carbonate

(cm) - Centimetre

(CTBT) - Comprehensive Test Ban Treaty

(D) - Absorbed Dose Rates

(DTA) - Differential Thermal Analysis

(E) - Energy

(EC) - Electrical Conductivity

(EDXRF) - Energy Dispersive X-Ray Fluorescence

(Eff. Dose) - Annual Effective Dose Rates

(ELCR) - Excess of Lifetime Cancer Risk

(ERICA) - Stand-alone software package that allows the user to make assessments of the exposure of non-human biota to ionising radiation from radionuclides in the environment

(G-BASE) - Geochemical Baseline Survey of the Environment

(GPS) - Global Positioning System

(GWe) - Giga Watt electric

(h/yr) - Horse per year

(HASL-300) - Health and Safety Laboratory (USA)

(Hex) - External Hazard Index

(Hin) - Internal Hazard Index

(NPP) - Nuclear Power Plant

(NR) – Natural Radioactivity

(^{7}Be) - Beryllium 7

(^{87}Rb) - Rubidium 87

(^{89}Y) - Yttrium 89

(^{90}Sr) - Strontium 90

(AED) - Annual Effective Dose

(HpGe) - Hyper Pure Germanium

(IAEA) - International Atomic Energy Agency

(ICRP) - International Commission for Radiological Protection

(ICRU) - International Commission on Radiation Units and Measurements

(I) – Intensity

(IM) - Relative intensity measured by the detector for the photopeak

(Iα) - Alpha Index

(Iγ) - Radioactivity level index (Gamma Index)

(KCl) - Potassium Chloride

(keV) - Kilo electron Volt

(mBq/m3) - Milli Becquerel per cubic meter

(MCA) - Multi Channel Analyser

(MDA) - Minimum Detectable Activity

(mg/kg) - Milligram per kilogram

(ml) – Millilitre

(mm) – Millimetre

(mSv) - Milli Sievert

(mSv/yr) - Milli Sievert per year

(OECD) - Organisation for Economic Cooperation and Development

(OML) - Oil Mineral Lease, Delta State, Nigeria

(P.D) - Percentage of Photon per Disintegration

(pCi) - Pico Curie, one trillionth of a curie

(pCi/g) - Pico Curie per gram

(pH) - Potential hydrogen

(QC) – Quality Control

(QAQC) - Quality Assurance and Quality Control

(r) - Correlation Coefficients Values

(R.E) - Relative Efficiency

(RAD7) - Instruments to measure radon in water

(Raeq) - Radium Equivalent Activity

(RAP) - Reference Animals and Plants

(ROI) - Region of Interest

(SNL) - Sandia National Laboratory

(SRS) - Savannah River Site, USA

(Sv/Gy) - Sievert/ Gray

(TAEC) - Tanzania Atomic Energy Commission

(TENORM) - Technologically Enhanced Naturally Occurring Radioactive Materials

(TF) - Transfer Factor

(TGA) - Thermo Gravimetric Analysis

(UAE) – the United Arab Emirates

(UNSCEAR) - United Nations Scientific Committee on the Effects of Atomic Radiation

(N.F) - Normalising factor

(NaI) - Sodium Iodide

(NCRP) - National Council on Radiation Protection and Measurements

(NDA) – Non-Destructive Analysis

(NDT) - Non-Destructive Tests

(nGy/hr) - Nano Gary per hour

(nm) - Nanometre

(NORM) - Naturally Occurring Radioactive Materials

(AEDE) - Annual Effective Equivalent Dose

(Bq) - Becquerel, unit of activity

(XRD) - X Ray Diffraction analysis

(σN) - Uncertainty due to counting

(σS) - Uncertainty due to the standard calibrating mixed source

(σW) - Uncertainty due to sample weight

(UNSCEAR) - United Nations Scientific Committee on the Effects of Atomic Radiation

(XRD) - X Ray Diffraction Analysis

(σN) - Uncertainty due to counting

(σS) - Uncertainty due to the standard calibrating mixed source

(σW) - Uncertainty due to sample weight

Chapter 1 Introduction

1.1. Preamble

Radioactivity exhibited by naturally occurring radionuclide is defined as natural radioactivity. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993; 2000; 2008), about 87% of the radiation received by mankind is due to natural radiation sources. Natural radioactivity has been determined in aerosols, food, building materials, underground water, and surface water and in a working environment (Shabaka et al., 2020; Merz et al., 2015; UNSCEAR, 2008, Umar et al., 2012). However, there are very limited studies on the evaluation and monitoring of natural and man-made radioactivity levels in the United Arab Emirates.

1.2. Research Problem

There are many sources of natural radioactivity on land, in water and generally in the environment of the United Arab Emirates (UAE). However, there are neither studies to comprehensively evaluate the sources and concentration of natural radioactivity nor the anthropogenic sources monitoring in the country. The results of this research project will be a first step in addressing the need of the UAE for a nationwide radiological surveillance program. Previous work on the subject for specific area recommended a detailed evaluation of radioactivity sources in the United Arab Emirates (Al-Hassani et al., 2004). Environmental analysis is one of the vital instruments to assess the impact of man-made activities on the environment, and such environmental analysis should serve as a baseline for the environmental impact assessment of the future nuclear facilities and installations, and the methods of determining radioactivity levels are well documented. The country has already begun to operate the nuclear power reactors of Barakah NPP. The first unit was connected to the grid in August 2020. It reached 100% power in December 2020 and entered commercial operation in April 2021.

1.3. Environmental Radioactivity

Radiation occurs naturally in the environment since the beginning of the Earth' formation, where radioactive elements are found in rocks, soil and water, in addition to cosmic radiation, which is one of the natural sources of radiation. All organisms are exposed to a certain amount of natural radiation resulting from the natural radioactive background, which is the basis for comparing other levels of radioactivity that humans can be exposed to from other sources resulting from human activities. (UNSCEAR, 2008; WHO, 2016).

The introduction of proliferated nuclear applications as a result of the advent of the nuclear age has led to the increase of population dose. Applications such as nuclear installations also cause increase of population dose. Also, human beings can be exposed to atmospheric radionuclides as a result of some traditional engineering activities, such as mining operations and their depositions, mine tailing, the use of phosphate-containing fertilisers and building materials and radioactivity released from burning fossil fuels (UNSCEAR, 2008).

Monitoring radiation background, which changes with increased human activities, is crucial in establishing a radioactivity baseline data. This data is vital in assessing pollution effect on human beings and the environment and also in obtaining environmental quality records for future use. Monitoring radioactivity in the marine environment requires the analysis of radioisotopes in seawater and sediments. There has been a great interest in radionuclides, both natural and artificial ever since the Chernobyl radiation accident. Due to an increase in public awareness, policy makers as well as scientists are interested in assessing the health of ecosystems, and many authors have investigated the ocean waters and marine sediments (Love et al., 2003; Hong G. et al., 2008).

1.4. Main Sources of Ionising Radiation

Two types of ionising radiation are known as natural and man-made. The highest proportion of exposure arises from naturally occurring sources. Of these are the cosmogenic isotopes and high-energy cosmic rays, also radioactive nuclides deriving from the Earth's crust. Global mean value of radiation exposure from natural sources is 2.4mSv/y, and it can vary from 1 to 10mSv/(Volgyesi, 2015).

In developing and developed countries only 0.6mSv (range 0–20mSv) of the annual effective dose of the population’s radiation exposure originates from man-made sources. Only around 2% arrives from atmospheric nuclear weapons tests, nuclear accidents, and nuclear energy production while the rest 98% is attributed to radiotherapy and medical diagnostics. We need to consider that the health care services in each country has a major factor in the amount of the effective dose due to artificial sources (UNSCEAR, 2000; WHO, 2016).

Figure 1.1 shows the percentage of population exposure to radioactivity produced by natural and artificial sources (WHO, 2016).

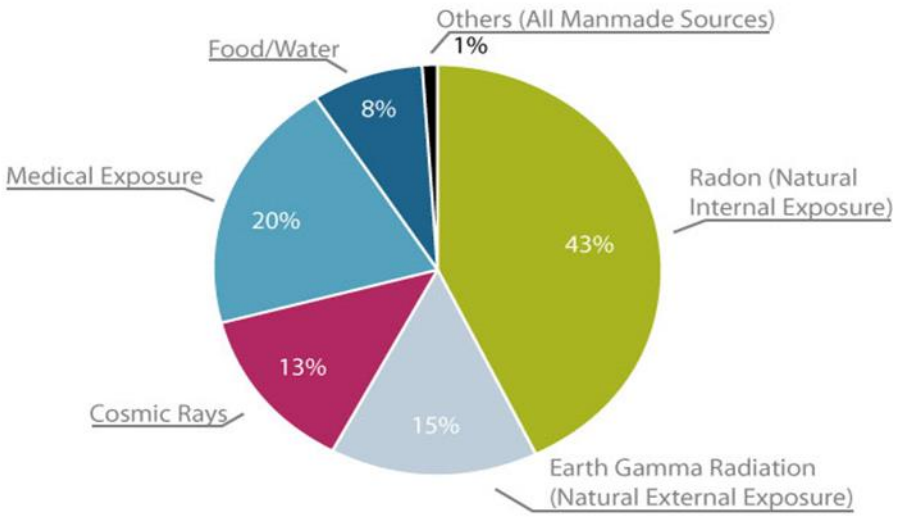

Figure 1-1 *Exposure of the population to radioactivity from natural and artificial sources*

At any location, background radiation levels are governed by any nuclear or industrial development nearby. Most of the time, these changes will give an indication of any environmental contamination or hazards that may interfere with the appropriate measures. In some countries, exposure to natural radiation is taken as a standard for radiation protection (UNSCEAR, 2000).

1.5. Natural Radiation Sources

It is important to assess the natural radiation levels and their impact on human beings upon exposure as they are essential in establishing a radiological reference baseline. The first and necessary step in any radiological monitoring program at the national or regional level is to study the natural radiation background and dose levels.

Natural radiation sources are crucial in terms of population dose as they are the main contributors to their levels. Natural radiation background levels have tendency to be steady with time and space except in some areas. It is vital to keep always monitoring this level of natural contribution. There are three types of natural radioactive sources: Cosmic rays, Cosmogenic radionuclides, and Primordial radionuclides (UNSCEAR 2000,2008).

1.5.1. Cosmic Rays

Cosmic rays are classified into primary and secondary. Primary rays come from outer space and are of high energy and can penetrate the earth's atmosphere. While secondary cosmic rays are of two types, neutron & ionising components. They also include electromagnetic

radiation, protons, electrons, neutrons charged particles and many others (Ferrari & Szuszkiewicz 2009).

1.5.2. Cosmogenic Radionuclides

Cosmogenic radionuclides (of half-lives ranging from minutes to millions of years) are produced primarily when atmospheric gases interact with cosmic rays' products. The most important of these radionuclides are ^{3}H, ^{14}C, and ^{7}Be, and of minor importance are ^{10}Be, ^{22}Na, ^{35}S, and ^{39}Cl. Radionuclide's concentration depends on atmospheric variables such as latitude, longitude, and time. (ATSDR, 2011; Dirks et al., 2016; Lin et al., 2016).

1.5.3. Primordial Radionuclides

Primordial radionuclides are considered to be the major contributor of the natural radiation sources and have existed in the earth's crust for many years. They can be classified as series and no-series radionuclides (UNSCEAR, 2000, 2008).

1.5.3.1. Series Primordial Radionuclides

This group of radionuclides decay in different decay routes and different half-lives and end up as stable isotopes. Three natural series headed by Uranium-238, Uranium-235 and Thorium-232 are shown in Figure 1-2. They are Uranium-238(Uranium-Radium) series, Thorium 232 Series, and Uranium-235 (Actinium) Series (Tykva & Berg, 2004, WNA, 2020).

The application of physiochemical or biochemical processes may lead to the separation of progeny radionuclides and that is due to the generic differences in chemical properties. (Ivanovich et al., 1992).

1.5.3.2. Non-series Primordial Radionuclides

These radionuclides decay and form a stable nuclide straightaway, Potassium-40 (^{40}K), vanadium-50 (^{50}V), cadmium-113 (^{113}Cd), and indium-115 (^{115}In) are the main isotopes. As far as population dose is concerned, the most important radionuclides are ^{40}K (gamma emitter) and ^{87}Rb (beta emitter). (UNCEAR, 2000, 2008; Omar et al., 2019).

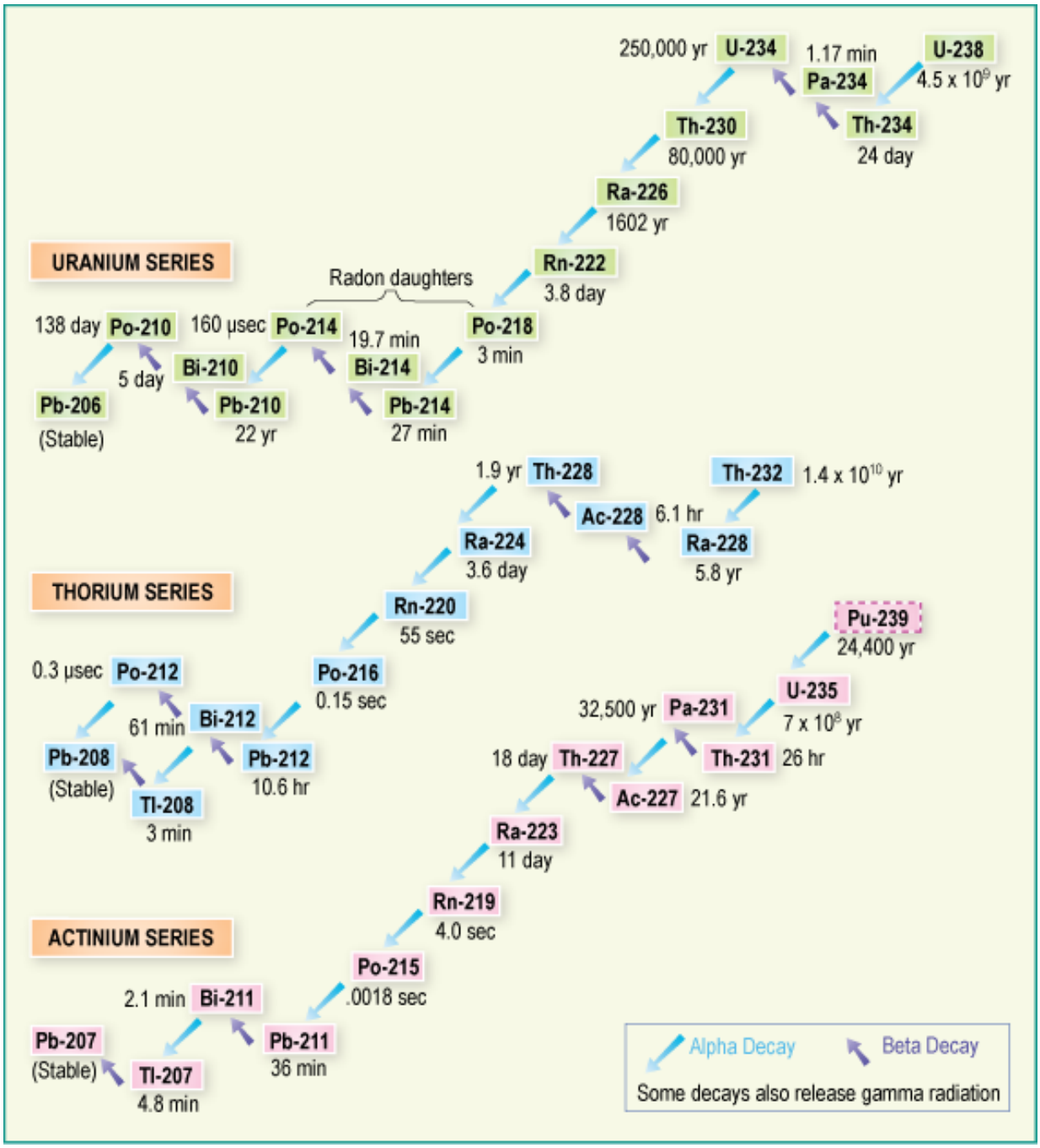

Figure 1-2 *The Three Natural Decay Series: Uranium-238(Uranium-Radium) series, Thorium 232 Series, and Uranium-235 (Actinium)Series (WNA, 2020)*

1.6. Main Properties of Terrestrial Radionuclides

The radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K are the most significant contributors to the mean annual effective dose received by humans among other terrestrial radionuclides. Their main properties are summarised in Table 1-1 (UNSCEAR, 2008; Manolopoulou et al., 2003).

Table 1-1 Main properties of uranium, ^{238}U, ^{235}U, ^{232}Th, ^{226}Ra and ^{40}K

Radionuclides	**U (uranium)**	**Th (thorium)**	**K (potassium)**	**Ra (radium)**
Atomic number	92	90	19	88
Main oxidation states	+2, +3, +4, +5, +6	+4	+1	+2
Main isotopes	**^{238}U, ^{235}U**	**^{232}Th**	**^{40}K**	**^{226}Ra**
Anthropogenic sources	Nuclear effluents, phosphate fertilisers, coal combustion. mining and milling	Fertilisers, uranium mining and processing, and coal combustion.	Fertilisers	coal combustion. fertilisers, uranium mining, processing
Health Effects	kidney disease, development of cancer	increases the chances of developing lung diseases and lung, pancreas, and bone cancer.	substitutes stable Potassium which means it is present in all living organs which metabolise K.	absorption into bone structure due to high radiotoxicity.
The data were summarised from the database of Mauring & Gäfvert (2013); Salminen et al. (2005).				

1.7. Man-Made Radiation Sources

Man-made radiation sources include nuclear and non-nuclear sources in which releases particles to the environment. Man-made radiation can be categorised according to the man activities to four types: nuclear tests, nuclear energy activities, medical-industrial uses, and research purposes. (UNSCEAR, 2000, Eisenbud & Gesell, 1997):

1.7.1. Nuclear Tests

In any nuclear explosion, a radioactive product settles down slowly on the earth's surface through what is called the fallout. The radionuclides resulting from the explosion are transmitted through the contaminated cloud, where first the heavy products are deposited close to the area of spread, and the cloud continues to deposit the lighter products away from the area of the explosion, and this leads to the spread of radioactive contamination to areas far from the area of the explosion. The transmission of the polluted cloud is affected by wind

speed and direction and other weather conditions such as rain and humidity, as well as affected by the geographical composition of the area. (Salminen et al., 2005).

1.7.2. Nuclear Power Plants

Rradioactive materials which produced through the day-to-day operation of nuclear plants is closely monitored especially in operations such as enrichment of uranium-235, production of power in nuclear reactors and, radioactive waste disposal (IAEA, 2005, 2013):

1.7.3. Medical Uses of Radiation

The application of radiation in medicine can either be diagnostic such as X-ray examinations, nuclear medicine applications, or therapeutic such as tumour treatment. It is this medical application that contributes to population doses of about 20-25%. (IAEA, 2014).

1.8. Radiation Exposure

Exposure by humans to radiations can either be external through radiation sources or internal through ingestion and inhalation. Everyday exposure to radiation originates from two sources, natural and manmade. The most abundant source of natural radiation is cosmic and radioactive sources in the earth's crust (UNSCEAR, 2000, 2008).

1.8.1. Exposure to Terrestrial Radiation

Terrestrial radionuclides in the earth's crust contribute to human's both external and internal exposures. External exposure is due to gamma rays resulting from ^{40}K, ^{238}U and ^{232}Th series decay. Indoor and outdoor exposure make up total external exposure. Human beings are exposed to gamma rays form nuclides present in soil or cosmic rays when they are present outdoors. Indoor exposure arises form Radon or thoron gas inhalation or their short-lived products (NCRP, 1992).

1.8.2. Exposure to Cosmic Rays

Ionising radiation, the result of the interaction of cosmic rays when they enter the earth's atmosphere, depends on altitude and latitude. At sea level, cosmic rays can be classified into either hard component (Muons and few Neutrons) and soft component (electrons and photon radiation). Mankind exposure to secondary cosmic radiation and cosmogenic radionuclides constitute either from internal or external exposure (NCRP, 1992).

1.8.3. Man-made Sources of Exposure

Exposure to manmade radioactive sources constitutes to only a third to that received from natural sources, around 80 mrem/y. Medical procedures make up the largest portion of exposure through manmade sources (NCRP, 1992).

1.9. Radiation Dose Assessment

Ionizing radiation represents electromagnetic waves and particles that can ionize. Ionizing radiation may be emitted in the process of natural decay of some unstable nuclei or following excitation of atoms and their nuclei in nuclear reactors, cyclotrons, x-ray machines, or other instruments. The photon (electromagnetic) component of ionizing radiation emitted by the excited nucleus is termed gamma rays and that emitted from machines is termed x rays. The charged particles emitted from the nucleus are referred to as alpha particles (helium nuclei) and beta particles (electrons). Irradiation of the human body from external sources is mainly by gamma radiation from radionuclides in the ^{238}U and ^{232}Th series and from ^{40}K. All these spectrometric measurements indicate that the three components of the external radiation field, namely from the gamma-emitting radionuclides in the ^{238}U and ^{232}Th series and ^{40}K, make approximately equal contributions to the externally incident gamma radiation dose to individuals in typical situations both outdoors and indoors. (UNSCEAR, 2000)

1.9.1. Radium Equivalent Activity

The nuclides ^{226}Ra, ^{232}Th and ^{40}K concentrations and their distribution in environmental samples are not uniform everywhere. Exposure to radiation has been standardised as radium equivalent activity Ra_{eq} in Bq/kg in order to compare the specific activities of samples containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. Radium equivalent dose (Ra_{eq}) is used to evaluate radiation hazards form materials such as ^{226}Ra, ^{232}Th and ^{40}K in Bq/Kg, and is defined as:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \qquad \textbf{Equation 1-1}$$

Where: C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, and this formula is based on the estimation that 1 Bq/kg of ^{226}Ra, 0.7 Bq/kg of ^{232}Th or 13.0 Bq/kg of ^{40}K produce the same gamma dose rate (Alaamer, 2012; Ramasamy et al., 2009; Sroor et al., 2002; UNSCEAR, 2008).

1.9.2. Absorbed Dose Rate in Air from External Gamma Radiation

In free air, exposure to natural nuclides and their gamma radiation is dependent on several factors, most importantly are the moisture and density of the ground and also the distribution of radioactivity. Absorbed radiation rate can be calculated using equation 1-2 (UNSCEAR, 2008):

$$D = R_k C_k + R_u C_u + R_{Th} C_{Th} \qquad \textbf{Equation 1-2}$$

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, and are given in table 1-2 for some radionuclides, C_k, C_u, C_{Th} are the concentration of ^{40}K, ^{238}U series and ^{232}Th series respectively, expressed in Bq/kg dry weight soil (Sam et al., 1997; UNSCEAR, 2000, 2008).

Table 1-2 Conversion factor for γ-ray 1 m above the ground for ^{40}K,^{238}U and ^{232}Th

Radionuclide	**Conversion factor (nGy/hr.per Bq/kg)**
^{40}K	0.043
^{238}U series	0.467
^{232}Th series	0.661

1.9.3. Annual Effective Dose

Annual effective dose (AED) can be calculated using equation 1-3 (UNSCEAR, 2000). Occupancy factor of 0.2 and conversion factor of 0.7 were proposed.

$$\text{AED (mSv/yr)} = D\ (\text{nGy/h}) \times 8760\ (\text{h/yr}) \times 0.2 \times 0.7\ (\text{Sv/Gy}) \times 10^{-6} \qquad \textbf{Equation 1-3}$$

1.10. Aspects of Sampling Techniques

Sampling and environmental analysis are aimed at obtaining the necessary data to describe the possible actions at certain times and places, so the first and most important step in this process is to collect valid samples. Under investigation, the sampling, number and number of sites must be taken for a clear purpose and a complete understanding of the problem to be solved or the information to be obtained taking into account the prevailing physical conditions in order to be able to obtain meaningful results that help in making a particular decision or action. (Chieco, 1997; EPA 2002).

1.10.1. Judgmental Sampling Designs

Judgmental sampling, or also known as a non-probability sampling technique in which the sample members are chosen based on the researcher's experience and judgment which is non quantified and statistical treatment of data can be highly biased. Purposive sampling and authoritative sampling are other names for this technology (EPA, 2002).

1.10.2. Random Sampling Designs

To accomplish such design, a designator is allocated for each location and samples are randomly taken. Such procedure is very functional in obtaining representative samples necessary for determining mean values. On the other hand, this procedure is not optimal for area mapping as it cannot provide guaranteed distribution of samples across the study area, as shown in Figure 1-3 (IAEA, 2004a)

1.10.3. Cluster Sampling Designs

In this type of sampling, specified number (n) of samples are taken using simple random sampling. In areas where measurements exceed threshold values, extra samples are required. Such sampling can be useful in tracking the selection probabilities for later sampling places thus furnishing an unbiased population mean. A representative example of such application is the is delineating the borders of a plume of contamination, as shown in Figure 1-4 (EPA, 2002).

1.10.4. Regular or Systematic sampling Designs

This design is one of the most common sampling methods and can be considered somewhat systematic. When the grid location is chosen arbitrarily, there will be an equal probability of choosing each member. Trans uranium contamination can be described as an intrinsic random function and thus can be represented as shown in Figure 1-5 (IAEA, 2004a).

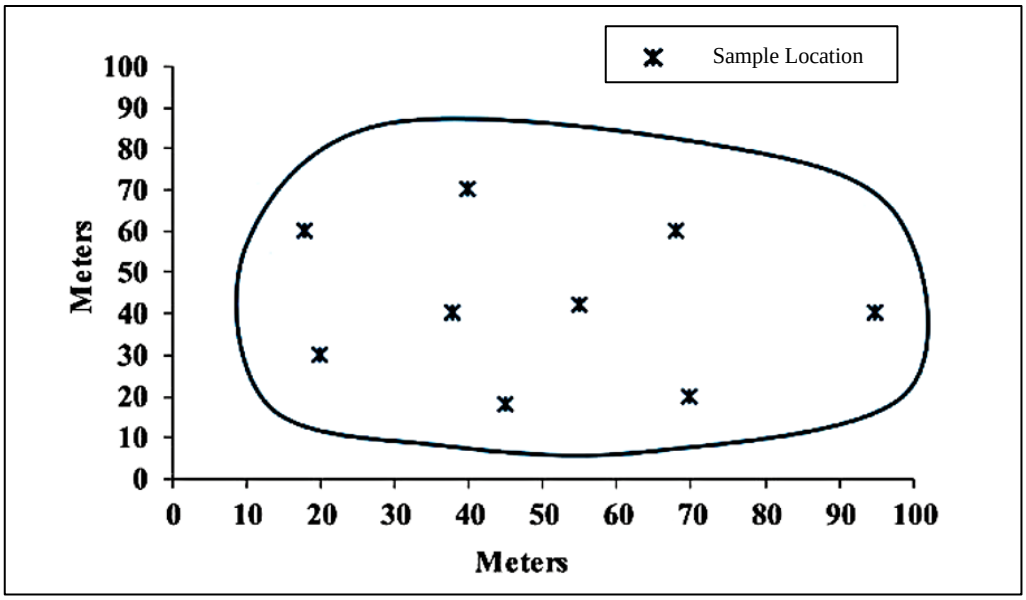

Figure 1-3 *Random Sampling (IAEA, 2004a)*

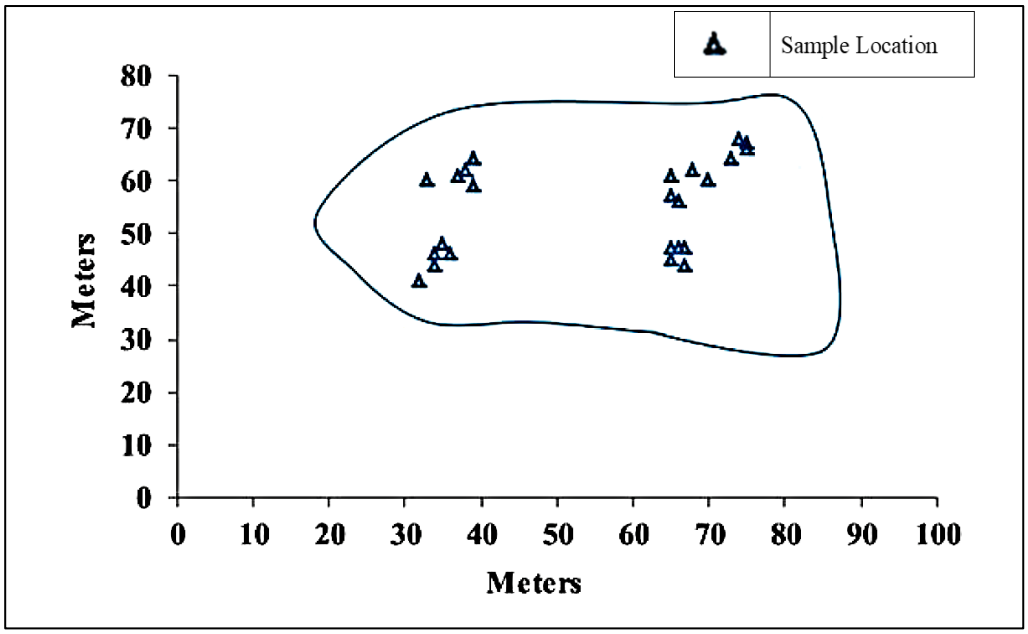

Figure 1-4 *Cluster Sampling (EPA, 2002)*

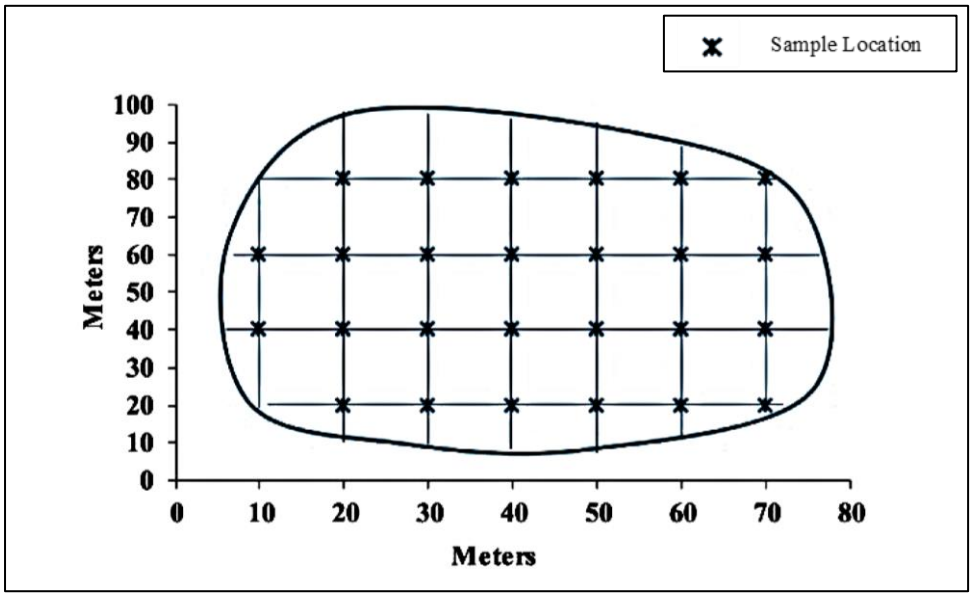

Figure 1-5 *Systematic Sampling (IAEA, 2004a)*

1.11. Statistical Calculations

1.11.1. Uncertainty

In nuclear analytical techniques, it is important to identify the uncertainty sources so that high quality data can be obtained. The standard deviation of any random process is known as the square root of the whole population i.e., $\sqrt{N}$. The total counts of any selected energy transition namely region of interest (ROI) is considered as N. However, the source of errors can be simply classified to uncertainty due to counting (σN), uncertainty due to sampling weight (σW), and uncertainty due to the standard calibrating mixed source (σS). The following equation can be used to calculate the combined total uncertainty (Ellison & Williams, 2000).

$$\sigma T = \sqrt{(\sigma N)^2 + (\sigma W)^2 + (\sigma S)^2} \qquad \textbf{Equation 1-4}$$

1.11.2. Minimum Detectable Activity (MDA)

The smallest amount of radioactivity that can be distinguished from the blank sample is known as the minimal detectable activity. If the count rate of a sample is roughly the same as the count rate of the background, the MDA is significant in low-level counting (Currie, 1984).

$$MDA = \frac{2.71 + 4.66 \times \sqrt{BG}}{t \times Eff \times V}$$ **Equation 1-5**

Where: t is the counting time, E_{ff} is the efficiency of the gamma energy line; V is the volume in litres.

1.12. The Importance of the Study

1.12.1. The Importance of UAE location

The UAE is in the south-west of Asia, specifically in the south-eastern part of the Arabian Peninsula between latitudes 22° 40' and 26° 00' North and longitudes 51° 00 and 56°00' East. To its north lies the Arabian Gulf, to its east is the Sultanate of Oman and to its south is the Kingdom of Saudi Arabia Figure 1-6. The total area of the UAE is 83,600 km^2. Dominant by desert, the land of the UAE is characterised by the predominance of Aeolian landform system. Its geological elements are varied including mountains, sand dunes coastal zones and drainage bays (Sherif et al., 2009).

Figure 1-6 *Location of the UAE*

Beyond the latitude and longitudes, UAE is located in the most unstable area on the world, too many wars happened in the last five decades, a lot of oil and gas industry located in this beaches and islands, many oil or aircraft carriers crossing the gulf in addition to nuclear submarines, many nuclear activities running on the Iranian side, either it is declared or nondeclared, very old Nuclear plant in Bushehr, many threats of bombing Iranian nuclear facilities, all this telling us about the location of UAE.

1.12.2. The Importance of the Coastline of UAE

In the UAE coastal line of UAE is the most important area in the country due to the following reasons.

There are six major cities of UAE; Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al Quwain and Ras Al Khaimah, most population, political and economic activities are conducted in this coastline. There are so many beaches which are very popular as people spend many hours there.

The presence of industrial activities, petroleum and oil industries, water desalination plants and nuclear power plants (two units are under gradual operation, and two units are under construction) located at the UAE coastal line.

The coastline of UAE is the first defender line against any kind of environmental pollution threats including radiation threats from the activities running in the water or in the other neighbouring coastlines.

1.12.3. The Importance of The Study

The importance of the coastline of UAE and the lack of a comprehensive study of the natural and anthropogonic radiation nuclides has driven the need of carrying out this surveillance study of the natural and artificial radioactivity levels to assess the radioactive pollution effect on the territory (soil) and marine environment (Gulf water, shore sediment).

In addition to what we have discussed previously, this study is of great importance from the viewpoints of radiological emergency and environmental impact assessment of nuclear power plants operation.

1.13. Aim of the Study

This study aims to assess the natural and artificial radioactivity levels in the water, shore-sediments and soil samples along the coastal borders of the UAE and islands to establish a comprehensive radiological baseline based on the measured and observed specific activity levels and to estimate the hazard indices such as absorbed dose rates due to the measured radioactivity in the collected soil and shore sediment samples.

1.14. The Objective of the Study

i. Assessment of the natural and artificial radioactivity levels in the water, shore sediments and soil samples along the coastal borders of the UAE and islands, and establish a comprehensive radiological map based on the measured and observed specific activity levels.
ii. Estimation of the hazard indices such as absorbed dose rates due to the measured radioactivity in the collected soil and shore sediment samples.
iii. Provide a database for public health evaluation from nuclear activities due to radionuclides and radioactivity levels observed in the study regions.
iv. Reference monitoring tool for future normal operation and releases of the nuclear facilities in the UAE.
v. Establish a baseline of radionuclides concentrations from which to judge the potential threat of accidental releases of radioactivity to the Arabian Gulf.
vi. Study radionuclides level releases into the environment to calculate and assess their impact (exposure, hazard indices and dose rate) on population.

1.15. Contribution to Knowledge

In the framework of the peaceful applications of nuclear industries and activities in the UAE and the surrounding regions and worldwide, this study is of great vision and provides the following crucial contribution to knowledge:

i. Establishment of the base data for environmental radioactivity levels in the UAE coastal area as a part of the global worldwide radioactivity monitoring target.
ii. Participation in the global signature radionuclides network monitoring as a tool of the comprehensive test ban treaty (CTBT) objectives.

iii. International Border monitoring against nuclear smuggling and illicit trafficking of orphan radioactive sources and nuclear materials.

v. Provide a radiological basline to assess any potential external pollution and releases into the waters of the Arabian Gulf due to neighbouring nuclear activities or any normal or deliberate leakage of radioactive liquid waste as a result of the passage of nuclear-powered submarines or aircraft carriers in the waters of the Arabian Gulf.

Launching a scientific base on which public radiation impact can be estimated to attain a sustainable development.

1.16. The Work Plan

The following road map summarises the required steps to achieve our objectives. The tasks and targets performed in the undertaking of this research are summarised in the following work plan:

i. Literature review for national, regional and worldwide radiological survey studies.

ii. Explorations of the area under study: Mapping of the area using Google maps, Mapping of the area using specialised maps, Selection of samples location from maps and exploration trips to the sites and Islands.

iii. Preparations to start the sample collection strategy: local knowledge and contacts, Preparation of transportation, sample collection equipment, and GPS devices calibration.

iv. Collection of samples from the pre-selected locations: field trips to the location (Gulf coast, Islands), collect samples using standards methods and mechanism, collection of soil, shore sediments, seawater samples from coastal areas collection of soil, shore sediments, seawater and bottom sediments samples from islands, sample numbering, tagging, marking, coding and labelling.

v. In situ radioactivity monitoring for all selected sites to assess the radiation levels and dose rate in comparison with the mean world value.

vi. Preparation of collected samples to be analysed, sample drying, sieving and packing in specific geometrical containers (100, 1000 ml capacity), preparation of the selected 79 samples to be mechanically analysed to know

silt, clay and sand fractions, preparation of the selected 79 samples to be analysed by X-Ray diffraction to identify major and minor minerals.

vii. Set-up calibration of the detection systems such as Sodium Iodide (NaI) and Hyper Pure Germanium (HpGe) spectrometers.

viii. Analysis of reference and standard IAEA materials for a quality control program.

ix. Determination of the natural radioactive isotopes in the soil and sediments samples (e.g., ^{238}U series, ^{232}Th series, ^{40}K) - by non-destructive Gamma spectrometers with their associated electronics.

x. Analysis of the collected samples for detection any man-made radionuclide (e.g., ^{137}Cs) based on their specific gamma energies.

xi. Calculation of absorbed dose rates, Radium equivalent, hazard index due to the natural radioactivity levels of the collected samples.

xii. Evaluation of the measured natural and anthropogenic radioactivity levels in the light of the international levels and limits.

xiii. Statistical treatment of the result and correlations.

xiv. Establishing a radionuclides levels baseline through developing a fingerprint approach. This can be achieved through collection of field data, laboratory analysis of samples and statistical correlations.

xv. Predication for assessment and remediation strategies in case of radioactivity pollutants detection in the studied regions.

xvi. Thesis writing, revision, conclusions, and submission with recommendations

Chapter 2 Literature Review

2.1. Preamble

Naturally Occurring Radioactive Materials (NORM) which are naturally present in some raw materials can be a source of problems in some industries. The presence of radioactivity in the environment arises from discharges from energy production (fixed and marine nuclear power plants), mining and processing of uranium, minerals, phosphate, oil and gas production, natural sources, or presence of contamination from many other applications. Therefore, there is a need to control discharges. Compliance with radiological criteria and a need to assess exposures to the population and estimate the radiological impact on the environment are a must (Gascoyne & Larocque, 1984).

2.2. NORMs in Sediments, Beach Sands, Soil and Water

Water and sediment samples were collected from Amang processing (Tin Mining) areas in Malaysia, were ^{238}U and ^{232}Th concentrations determined using a hyper pure germanium (HPGe) detector coupled with a multi-channel analyser (MCA). In water samples, Uranium results showed maximum mass of 6.64 ppm, activity concentrations 78.53 Bq/L, while in sediment samples maximum mass were 69.75 mg/kg and activity concentrations was 860.57 Bq/kg. In Thorium water results, the maximum mass and activity concentrations of thorium in water samples were 1.71 ppm and 6.90 Bq/L, while in sediment samples were 157.73 mg/kg and 637.61 Bq/kg respectively. ^{238}U and ^{232}Th concentrations in sediment samples were higher than in water perhaps due to insolubility of these radionuclides in water. Also, samples collected from pond water recycle systems, open and close, revealed that both nuclides were higher in close ponds, and both were higher than background levels suggesting that this processing plant has enhanced the natural radionuclides contents in water and sediment. (Nasirian *et al.* 2008).

Natural radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K in one hundred surface soil samples were collected from various areas of Riyadh city, Saudi Arabia High resolution gamma spectrometry was used for determination and results were compared to global levels. Mean measured activity concentrations were ^{226}Ra (14.5±3.9 Bq/kg), ^{232}Th (11.2±3.9 Bq/kg) and ^{40}K (225±63 Bq/kg). (Alaamer, 2008).

In a study, Radenkovici et al. (2009) have estimated radiological risk caused by the presence of natural as well as man-made radionuclide in areas such as seaside and riverside public beaches. Samples collected from the Lido Beach on the sediment Great War Island, Danube River in Belgrade, Serbia were collected and analysed. Human exposure to terrestrial

radiation as well as to sands used in building construction were measured. Standard gamma spectrometry procedures were used to determine specific radionuclides in sand samples. Three different radiation hazard indices were used to determine the radiation hazard from using sand as a building material, the rate of gamma dose rate absorbed in the air, and the annual effective dose outdoors were calculated. The results obtained are close to industrial standards.

Similar studies in coastal waters of Slovenia, Croatia and Albania, Petrinec et al. (2012) natural and artificial radionuclides were studied. Also, samples from deepest part of the Adriatic in South Adriatic Pit and Otranto strait were collected between 2007-2011. These locations were chosen as they represent major geological and geographical features of this part of the Adriatic Sea and possible coastal influences. Gamma spectrometry was used for measurements. Similar activity concentrations of the examined radionuclides to those reported for the rest of the Mediterranean Sea were observed.

The concentrations of certain radionuclides around Lebanon have been documented El Samad et al. (2012). Samples (sand, sediment and seawater) from different locations were collected and analysed for the duration 2009-2010. ^{137}Cs and ^{226}Ra in marine samples were below the minimum detectable activity. Sea water uranium activity for the years 2009 and 2010 at the three sites were in the ranges of 46:68mBq/L, and from 44:57mBq/L for ^{234}U and ^{238}U respectively. During 2010 ^{210}Po in sediment samples was 4 - 10 Bq/Kg dry, while ^{210}Pb was 8 - 19 Bq/Kg dry.

Typically, river water on its course dilutes and moves radionuclides to sink at the bottom of the river hence affecting sedimentation. ^{40}K and ^{137}Cs activities for both Ibrahim and Awwali rivers were 2.5 Bq/Kg and 0.2 Bq/Kg respectively, and both were below international acceptable levels. Samples from Ibrahim River showed activity concentration of ^{214}Bi and ^{214}Pb of 11.9 and 13 Bq/Kg respectively, while for ^{212}Bi and ^{212}Pb were 6.5 and 5.4 Bq/Kg respectively. As for Awwali river, the respective results were, 8.9 and 10.3, 6.3 and 5.2 Bq/Kg. Results also showed that mean annual radionuclide concentrations were similar to previous years.

Activity of naturally occurring radionuclides were studied in the Rajbari district of Bangladesh. Results revealed that this area was not hazardous as compared with world available literature data and pose no effect on the environment. The outcome of this study

provided valuable information about radiation hazard and the monitoring of environmental radioactivity.

Natural radioactivity of ^{238}U, ^{232}Th and ^{40}K were studied in in Qarun Lake located in the deepest part of El-Fayoum depression at the western desert, South Cairo-Egypt., El-Sayed (2014). This study aimed at assessing radioactivity baseline, providing radiation dose rate information in agricultural land around the lake and also developing natural radioactivity distribution maps.

Natural radioactivity levels in Aden, Yemen were studied, Harb et al. (2014). Soil and water samples were studied to determine ^{226}Ra, ^{232}Th and ^{40}K concentrations. Results showed that they were within reported elsewhere in the country and in other countries with similar environments. Radiation hazard indices were also dealt with in this study and showed normal levels. Further studies were recommended by the authors for determining doses to the population from other radiological sources in Aden.

Activity concentrations of ^{238}U, ^{232}Th and ^{40}K, and ^{137}Cs in Bethlehem Province of the West Bank in Palestine have been studied, Abu Samreh et al. (2014). In total fifty soil samples are analysed. Results were comparable to, or even below international levels and it is fair to say that these soil zones have normal levels of natural background radiation.

Using soil, water and coastal sediment samples from Marsa Alam Shalateen area, Red Sea coast, Egypt, a study provided basic information about the radiation level in the area and they assessed the potential radiological hazards. Arafat et al. (2017).

^{226}Ra (^{238}U) series, ^{232}Th series, ^{40}K and ^{137}Cs radionuclides were studied in environmental samples using Hyper-Pure Germanium (HPGe) detector. The study concluded that the concentration of ^{137}Cs in all samples was less than the detection limit according to the analyses used, and this applies to all water samples for ^{232}Th nuclide. Ground and sea water samples were clear of ^{226}Ra activity concentration. All fresh waters in that area founded safe for drinking except one place called (Al Gaheliya) which showed concentration of ^{226}Ra were higher than the concentration levels standards of WHO. For soil samples, the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the carbonaceous, siliceous and sediment (calcareous) samples did not impose any risks to the public, except one site; (Marsa Alam-Shelateen Road km 33), where the representative level index and absorbed gamma dose rate exceed the maximum permissible limits.

2.3. NORMs in Air Pollution

In the report on environmental monitoring for radionuclides in air by Sandia National Laboratory (SNL), Franke (2007). The authors monitored the release of fifteen sources of radioactive materials in air in the United States and concluded that the releases varied in number and size were not the same annually. The researcher also found that there are sources of radiation in addition to the sources he touched upon, such as stored nuclear weapons and buried nuclear materials.

In their operation, thermal power plants can produce ash containing high level of radioactivity. It can impose a health hazard to workers within the plant and also people living nearby. The effect of ash can be through fly-ash releases, fly ash depositions and fly-ash industrial utilisation. This study was conducted by Pandit et al. (2011) in three power plants in India. Results showed that annual external effective dose from fly ash was high as compared to other background areas. The predominant attributor to risk from fly ash was from ^{232}Th due to its high concentration in the ash. Data can be helpful in other fly ash studies in various applications.

Nuclear plants, their proposed planning and construction in the area of Eastern Mediterranean and also in the Middle East has been the focus of a study by Christoudias et al. (2014). The study aimed at assessing the risk associated with such activities. The authors concluded that the areas in the vicinity of such plants are at the highest risk and medium to long term transport into the atmosphere does not exhibit uniform dispersion. The study was conducted in area prone to earthquakes.

Countries especially to the south and east of such region are at high risk from such plants, and the study made importance of the fact that accidents at any of these plants could have significant trans borders effects.

The authors insisted that it is vital to assess the aftermath from nuclear plants accidents in such areas especially ones of high seismic activities as well as other natural and human activity-related hazards. Such awareness is needed to have an emergency response plan at times of accidents.

Three residential areas in Chittagong city, Bangladesh were selected to study the radiation hazard from NORMs and the anthropogenic isotope ^{137}Cs Rashid-Nizam et al. (2015). Soil samples from these areas were collected and analysed. NORMs in soil samples from these areas were more or less comparable concluding that radiological content of the soil was

independent of the nature of landscape being either hilly or plane land. Results also concluded that soils had the same uniform nature, also ^{137}Cs concentration in soil was too low to cause any health risk hazard and it was mainly present from atmospheric fallout.

The moss plant is a useful tool to assess atmospheric pollution due to the fact that it can absorb nutrients from the atmosphere and store many trace minerals. In a study to determine the deposition of uranium and thorium into moss plant, a study was carried out Arshad et al. (2016) around Manjung districts, Malaysia. The enrichment factor for these nuclides was calculated since it was useful in predicting if the elements would have an additional contamination from the anthropogenic activities or not.

2.4. NORMs in Building Materials

When rocks and soils are processed to produce building materials, their content of radionuclides is either kept in the final product or released to the atmosphere thus creating exposure hazard to the public. Special interest is focused on ^{238}U, ^{232}Th and ^{40} K. NORMs in building materials can affect the body through their gamma rays or through the inhalation of radon gas from decay products released from building materials.

Natural and manufactured building materials used in some areas in Saudi Arabia have been investigated, El-Taher (2012) where samples were collected from construction sites as well as the local market. All building materials test have shown values lower than those adopted by the OECD. All test samples showed low levels of absorbed dose rate in indoor air when compared to international levels and OECD's.

Coal slag and fly ash have been qualified to be used in building materials in Hungary. In order to assess their impact on human environment Völgyesi (2015) has conducted his study. Twenty-nine building materials were selected for this study, only seven coal slags were considered harmful and impose risk having high levels of ^{226}Ra. When coal is burned in power plants to produce electricity, coal slags are formed which are rich in radionuclides.

Granite is a widely used building material in parts of the Middle East. In an attempt to study its natural radioactivity in local and imported specimens Al-Zahrani (2017) carried out his study. Resultant data were lower than other countries in the region and also international levels and can be useful in developing standards and guidelines for such materials.

2.5. Natural and Anthropogenic Radionuclides Transferred to the Environment

Nuclear activities impact on the global environment stems from the radionuclides release into the environment. Effluent release from such activities can be assessed through either comparing them to natural release or with release from other sources such as the coal fuel cycle or nuclear weapons production and testing operations.

In 1986 a terrible nuclear accident occurred in Chernobyl Nuclear Power Plant. It happened near the city of Pripyat, north of the Ukrainian Soviet Republic. Several studies have been carried out to assess its impact locally and in neighbouring countries. In Sweden Tesfatsion (2012) has carried out a study on soil and grass samples of pastoral lands aiming at analysing activity concentrations of natural radionuclides and ^{137}Cs from Chernobyl accident. The main concern was to determine their transfer factor from soil to grass and finally to milk.

Higher concentrations of radionuclides in general and^{137}Cs in specific were found in these areas. This was attributed to man-made deposition and in this case the accident. All records were higher than those suggested by UNSCEAR. All study areas except for one showed positive correlation between activity concentration of radionuclides in soil and radionuclides activity in grass. In some parts of the country, ^{137}Cs from Chernobyl had a great impact on the total annual effective dose rate.

The Savannah River Site in South Carolina, USA was built in the 1950's for the purpose of refining nuclear materials to be used lately in the manufacturing of nuclear weapons. The impact of this installation on the environment was assessed in a study by Jannik et al. (2013). Their results revealed that despite many radionuclides had been released to the environment due to its operational programmes, yet they impose little risk to the public.

Although humans are constantly exposed to natural radiation yet certain activities such as oil exploitation and exploration in Nigeria has considerably increased such levels. Of such activities are drilling, oil spillage and gas flaring. Oil spells has led to surface water contamination in areas of Niger Delta. Despite of the high level of oil exploration activities in this region yet very few studies are made to determine the radiological hazards indices in soil/sediment and water.

Ajibode et al. (2013) evaluated the radiation hazard indices due ^{226}Ra, ^{228}Ra, ^{232}Th and ^{40}K radionuclides in the Delta State, Southwest of Niger Delta region of Nigeria. Data showed raised levels of radionuclides which could be the result of oil activities in the area. Soil and

sediment/sludge radiation indices were above the permissible levels. According to the authors, measures must be taken to prevent accumulative dose concentration with time.

2.6. Naturally Occurring Radiation in the Middle East Region

In recent years there has been some inspiration to acquire nuclear technology in countries of the Middle East. Several plants have been proposed in some countries while others have already operational plants. Manmade radioactivity can be generated from several sources such as energy production, nuclear medical applications and either industrial or agricultural applications. These manmade radionuclides find their way into the environment via several paths such as discharged effluents from nuclear plants, nuclear weapons testing facilities or through nuclear accidents. All the above only contributes to 15% of human exposure, while the rest, 85% comes from NORMs (WNA 2011). Such discharged materials can be deposited in several places including soil. Industrial processes involving NORMs can carry radiological risks through processing of such materials, so assessing such risks is pivotal. Countries across the world have a great interest in establishing baseline terrestrial radiation level. There have been some attempts for such studies in the countries of the Middle East, yet unfortunately they are few in number and scattered and there is a need for more solid studies. Here are some examples of studies found in the literature:

2.6.1. United Arab Emirates

The United Arab Emirates is considered a country with the prominent level of social and economic growth and consequently, a significant greenhouse gas producing country, so it is imperative to introduce a clean and efficient source of energy in the place. The UAE government agreed to have the first safe, peaceful, and sustainable nuclear power program in the region. The UAE's nuclear power plant is expected to provide 25% of the country's electricity needs and will save an estimated twelve million tons in carbon emission every year. Preliminary studies on radiation background level are necessary and have to be provided prior to the construction of any nuclear facility in any country. Such an investigation would be greatly received as a provider of background data resulting from the impact of nuclear facilities on the environment.

In preparation for the first nuclear reactor in UAE, a comprehensive study by Federal Authority for Nuclear Regulation, FANR was published and considered to be a baseline for NORMs in the UAE, FANR first report 2015. This study could be considered of as particularly important on both national and international levels for many reasons. The

assessment of the agricultural soil is necessary for policymakers to evaluate the state of the soil as it could represent a risk to the human and environment. The determination of the radioactivity concentration in the soil is essential to set a baseline level for the current situation. In case of any accidental release of any radioactive materials in the future, it is traced by comparing it to the baseline level, and the trend by time could be established. As expected, none of the naturally occurring radionuclides exceeded the reference levels set in FANR regulations and in general, the dose rates in the United Arab Emirates are very low when compared to most other countries in the world. The mountainous areas of the United Arab Emirates near the Oman border and some localised areas in the Al Dhafra region of Abu Dhabi have higher gamma dose rates than the coastal regions. Low levels of Cs-137 were observed in almost all soil samples. This is normal and consistent with expected concentrations due, primarily, to residual fallout from past atmospheric nuclear weapons testing. No other man-made radionuclides were observed. Extensive data were published in this report.

2.6.2. Sultanate of Oman

The sultanate of Oman occupies most of the southeast corner of Arabian Peninsula. Few studies have been published on NORMs in the Sultanate of Oman. Natural radioactivity presence in the environment depends on the geology and geography of the area.

A study by Al-Harmali A., 2020, has provided a baseline data of radiation in fifteen locations in northern Oman. The terrestrial gamma radiation level throughout the Sultanate of Oman was determined (Goddard C.C. 2002).

2.6.3. State of Qatar

Up until recently the literature lacks solid peer reviewed studies of NORMs and related issues in the State of Qatar. In 2010 a study focused on determining radioactivity concentrations of NORMs, as well as technically enhanced levels of radiation in soil samples all over Qatar was carried out Al-Sultani et.al, 2010. Six various locations across Qatar were selected for this study. Soil samples were collected and analysed to create activity concentrations levels of ^{235,8}U , ^{232}Th and ^{40}K. Data showed normal background radiation levels for all areas but one and the authors recommended further studies.

2.6.4. Kingdom of Bahrain

Unfortunately, very few publications on the NORMs in Bahrain are available. In fact, there is only one major study, Husain H, Sakhnini L. 2017. Dealing with the impact of oil and gas industry on NORMs levels. A set of four residential areas were selected for such a study, two experimental locations in areas with high oil and gas activities, against two control areas where there were no such activities. Noticeably high radiation levels were recorded in the selected areas which might be due to the geological constituent of the earth's crust being one of the contributors to high levels. However, the presence of extensive oil and gas operations including transportation is thought to be the largest contributor to such high radiation levels evident by the difference in levels between areas where such activities.

2.6.5. Kingdom of Saudi Arabia

In a study conducted in Riyadh, Saudi Arabia, 100 samples of surface soil were collected and analysed to measure the radioactive concentrations of ^{226}Ra, ^{232}Th and ^{40}K using a high-resolution gamma ray spectrometer. The activity concentrations mean in this samples were found to be 14.5±3.9Bq/kg, 11.2±3.9Bq/kg, and 225±63Bq/kg, for of ^{226}Ra, ^{232}Th, and ^{40}K respectively. Mean values founded of radium equivalent activity, air absorbed gamma radiation dose rate, and external radiation hazard index were 47.8Bq/kg, 23.3μGy/h, and 0.13Bq/kg, respectively. The study calculated the annual effective radiation dose which was 0.14mSv/y. (Alaamer , 2008).

In 2004, researchers studied radionuclide concentrations in sediment samples collected from the Persian Gulf, Saudi Arabia, the mean activity concentration of ^{137}Cs was 4.6 Bq/kg dry weight (Al- Kheliewi et al., 2007).

Generally, natural radioactivity studies or surveys are very little and scattered, either in air or even in soil in the Kingdom of Saudi Arabia. Although there are some studies in the literature mostly on specific parts of the kingdom and also on the Red sea coastline. A comprehensive study of the NORM baseline of Saudi Arabia is much required.

2.6.6. State of Kuwait

A study was carried out in Kuwait, (Uddin S. et.al., 2015), where ^{210}Po, ^{210}Pb, ^{137}Cs, ^{90}Sr, and ^{3}H baseline measurements in Kuwaiti waters were reported. Several marine organisms, especially Marica marmorata had high concentration of ^{210}Po, although there might be a seasonal drop in concentration when phytoplankton and macroalgae mass were abundant.

The concentration of ^{137}Cs in sea waters and in fish were low, thus this radionuclide level can be used as an indicator for any future release in the region. It is only fair to mention something about depleted uranium. Depleted uranium (DU) munitions have been used in several conflicts around the world, one being the Gulf war in 1991 and the IAEA has published a report for that purpose (IAEA, 2003). Based on the measurements carried out in this report, the followings were outlined:

i. No one in Kuwait has been identified to have received a dose from depleted uranium, hence it does not pose any radiological threat to the Kuwaiti population
ii. Also, exposure to DU residues very low and its annual radiation is negligible.
iii. In areas where DU might exist, their orders are just in the order of few micro sieverts. This is well below levels recommended by IAEA and well below the dose rates received by Kuwaitis from NORMs.
iv. The only possible way of possible exposure of radiological significance is the prolonged skin contact with DU.

2.6.7. State of Iraq

Although the presence of NORMs in Iraq and their effect on living matter has been studied extensively and many articles have been cited, a comprehensive study on the whole country is yet to be presented.

Iraq has had its share of wars and conflicts from 1980 when the first Gulf war started between Iraq and Iran followed by the second Gulf war in 1991 following the Iraqi invasion of Kuwait and the last war in 2003 when America invaded Iraq. International data were published on the use of depleted uranium in these wars. In their report, NGO Coordination Committee for Iraq, 2011. Reported that the use of depleted uranium and its contaminations as well as other military related pollution activities were the main causes of sharp rise cases of congenital birth defects and cancer cases in Iraq. Despite all that and thirty years down the line no credible extensive study has been developed to deal with this particular issue.

Radiological risks in the soil of Al-Samawah desert in southern Iraq were determined, Ali AM et. al 2019. Depleted uranium was assessed, and natural radioactivity was monitored in northwest of Iraq, Salama E. et.al. 2019. Other cities, such as Najaf, Kirkuk Basrah and Hila and many others were reported where NORMS were studied and reported.

2.6.8. Islamic Republic of Iran

Several studies have been published on background radioactivity across several cities in Iran and in most cases, levels were below or near international levels with one exception, Ramsar city in the northeast part of the country. This city has one of the highest NORMs in the world, Ghiassi-Nejad et.al. 2002, and in some areas of this city background levels are ten time and even higher that those permissible for radiation workers in Iran and is evident in some local food stuffs. The main cause of this high levels is the presence of ^{226}Ra in natural hot water springs which is brought to the surface through geological activity. People living in areas of high background radiation levels showed negative changes at cellular level, yet this was not the case in Ramsar city. It seems that exposure to higher levels of radiation over time can be helpful in providing a flexible response.

In another study, Shahbazi-Gahrouei D. et.al. 2013, natural radiation in Iran was compared to other countries and reviewed. Data showed that background radiation reported values of 1.24 times the global mean value and based upon that, the authors recommended the need for regularly monitoring and updating natural radiation data.

Chapter 3 : Methodology and Experimental Work

3.1. Preamble

The analysis of radioactivity is a challenging field. Both the sources of radioactivity (e.g., natural and man-made radionuclides) and media within which the radionuclides may be found, can present themselves in a wide range of complexities, some radionuclides can decay in different modes. The presence of more than one radionuclide in a sample with appreciable activities can further complicate analysis. In any analysis of radiation, some factors might facilitate or complicate the analysis; these factors are common in the radiation processes, such as the different parent-daughter nuclide decay schemes, equilibrium between parent and daughter radionuclides, and the rates of decay that radioactive nuclides undergo can affect the analysis. The problem of radioactivity analysis may be confounded further by the wide range of chemical and/or physical media (i.e., sample matrices) from which the nuclear radiation may emanate (Knoll, 2010).

A good understanding of the properties of nuclear radiation, how radiation interacts with matter, and other properties such as the half-life, decay schemes, decay abundances, and energies of decay; helps to choose the preferred type of detector to be used in any radiological analysis. The properties of nuclear radiation and the mechanisms whereby nuclear radiation dissipates its energy in matter, form the basis for the methods of detection and measurement of radionuclides (Knoll, 2010). Throughout this thesis, the author is going to furnish the techniques used in this important study. The author is eager to select the most suitable state-of-the art measuring technique for each radionuclide in order to reach the highest possible confidence and accuracy of the obtained results.

3.2. General Features of the Study Area

The UAE is one of the states in the Arabian Peninsula, at the southeaster tip of it between 22_ 500 and 26_ north latitude and 51_ and 56_ 250 east longitude (Figure 3-1). Politically it is composed of seven Emirates, namely, Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al Quwain, Ras Al Khaimah, and Fujairah. The UAE total area is 83,600 km^2, Abu Dhabi Emirate area is 77,000 km^2 which consider the largest among other emirates, major ecosystems component in Abu Dhabi is the coast, numerous islands, mountainous areas, gravel plains, and sand desert, nearly 80% of its area is desert (Figure 3-1) show location of Abu Dhabi Emirate in relation to other Emirates. Hundreds of islands in the Gulf belong to UAE, of which 200 are located in the Emirate of Abu Dhabi itself. (Abdelfattah & Shahid, 2007, Shahid *et al.*, 2004).

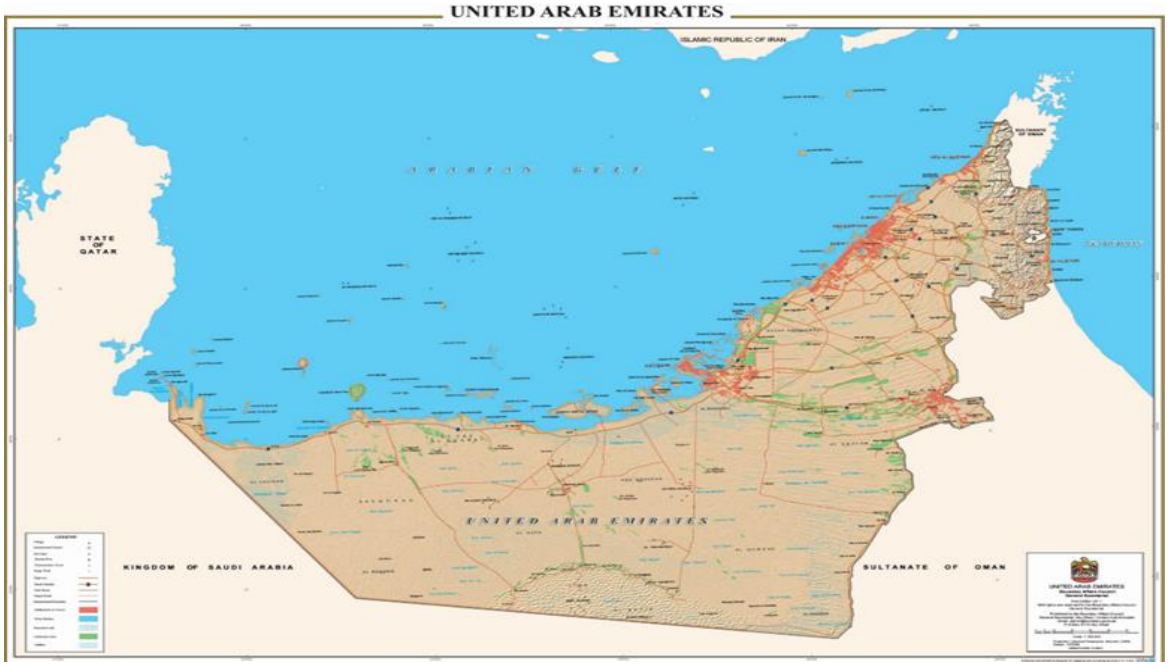

Figure 3-1 Map of the United Arab Emirates (UAE).
www.government.ae

3.3. Sampling

This surveillance study covered the coastal border of the UAE as well as some marine islands, it was conducted in the period of April till September 2009. The following steps explain in some detail all the procedures that took place before the start of the sample collection process, through collection and coding, until reaching the laboratory and preparing the samples for analysis.

3.3.1. Preparation for Sampling trips

Explorations of the area under study: Mapping of the area using Google maps, Mapping of the area using specialized maps, Selection of samples location from maps based on the systematic sampling method. Figure 3-2 showing the preselected locations of sampling stations selected and marked with red spot in an ordinary map and Figure 3-3 showing a screen shot of Google Earth program with the preselected samples location in red spots.

The systematic sampling method was used for sampling location selection because it is often used in environmental applications to delineate the extent of contamination and to define contaminant concentration gradients, it is relatively easy, practical, and convenient to implement in the field, and provides better precision like smaller intervals and more complete coverage of the target population than other sampling technics (*IAEA, 2004a, EPA, 2002, IAEA, 2019)*

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. Considering the factors mentioned previously, and since the geological structure is the same along the coastline, the length of the coast on the Arabian Gulf is about 650 km, therefore, I choose the stations to be at an interval of ten km between each station and the other.

Preparations to start the sample collection strategy: establishing a team to support in sampling process, train them and make sure they have all necessary knowledge and equipment, collecting local knowledge about the area of sampling, and contacts, Preparation of transportation which include vehicles, aircraft, and marine transportations, prepare sample collection equipment, GPS devices calibration. Figure 3-4 showing the author with sampling team while Figure 3-5 showing the transportations vehicle and boat for islands locations.

Collection of samples from the pre-selected locations: field trips to the location (Gulf coast, Islands), collect samples using standards methods and mechanism, collecting of soil, shore sediments, seawater samples from coastal areas collecting of soil, shore sediments, and seawater samples from islands, sample numbering, tagging, marking, coding, and labelling.

A total number of 79 sampling stations were selected for the samples collection, in each station, three types of samples collected, Soil (S), Shore Sediments (SS) and Seawater from the Arabian Gulf (W), all three types been collected on the same line to each other. The three different types of samples been codded with letters and number of the sampling station for example, in station 1 we collected S1, SS1 and W1. Figure 3-6 showing the sampling tools, the detailed sampling sites are presented in Table 3-1.

It should be mentioned that samples were collected from soil, sediment, and Gulf water, but no air samples were collected, the evaluating of external exposures from naturally occurring radionuclides in air can be calculated from measurements of the concentrations of the relevant radionuclides in soil (UNSCEAR, 2000). The other reason is that sample collection took place before the establishment of the Barakah Nuclear Power Plant, meaning that there are no radioactive emissions, and therefore, collecting air samples is of no need at that time.

3.3.2. Collecting of Shore Sediments and Soil Samples

A template of 25 cm^2 area and a depth of 5cm were used to collect soil and shore sediment samples, as shown in Figure 3-6, at each point; three sub-samples were collected and mixed to insure a homogeneous representative sample, then these samples were packed in plastic bags, tagged and numbered, soil samples were collected from the area outside the tidal range, while the beach sediment samples were collected from the area covered by the tidal range. (IAEA, 2019, 1989; Keith, 1991).

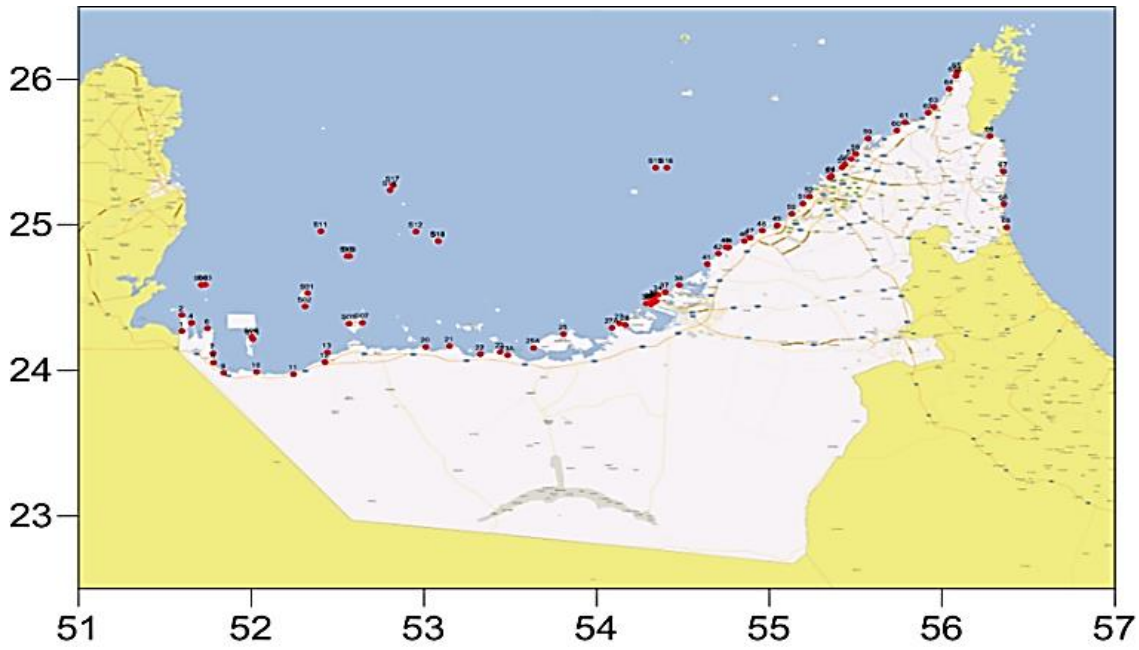

Figure 3-2 Map of the UAE Showing the preselected Sampling Locations of the Studied Areas in red spots.

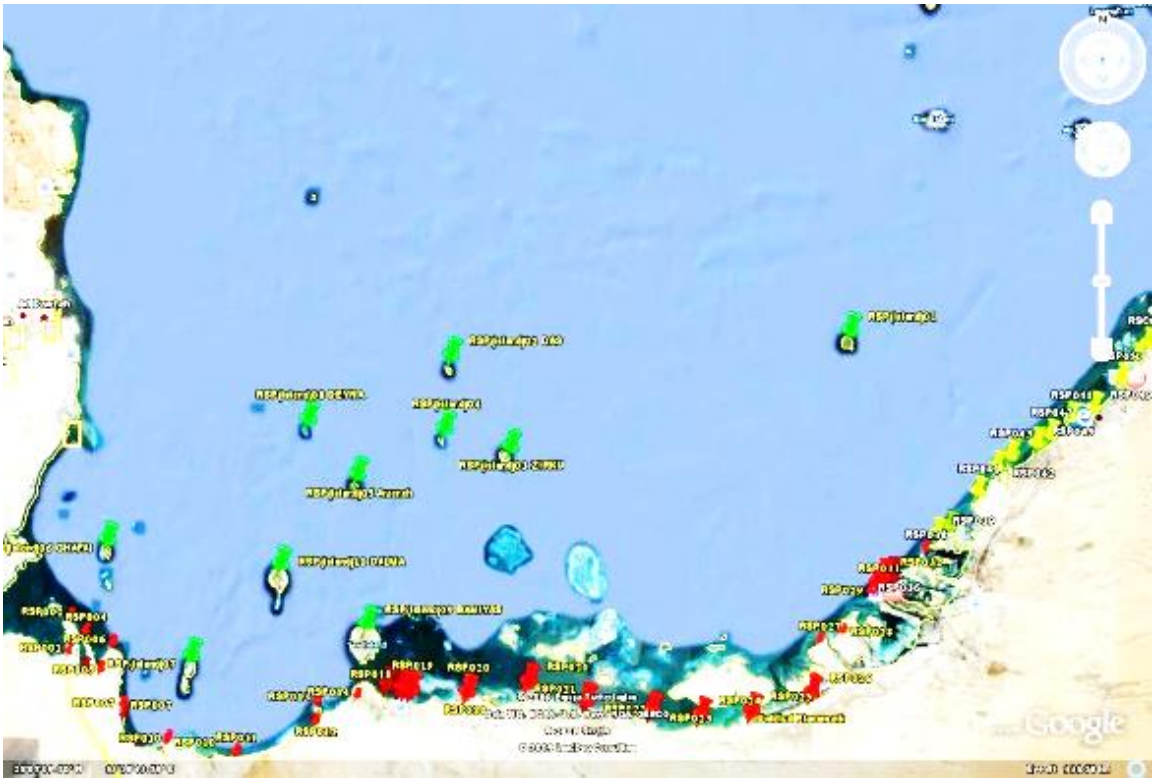

Figure 3-3 Screen shot of Google Earth Map Program showing the preselected sampling location of the studied area in red spot

3.3.3. Collecting of Gulf Water Samples

The Gulf water samples were collected from the surface beyond the tidal area, filtered with membrane filter 0.45µ, then immediately acidified with (11M) Hydrochloride at the rate of 10 ml per liter of the sample to avoid the adsorption of radionuclides on the walls of the container, stored in polyethylene bottles. (Blanchard et al., 1985; IAEA, 1989)

3.4. Samples Preparation for Analysis

3.4.1. Soil and Shore Sediments samples Preparation

To perform gamma analysis, all shore sediment and soil samples were prepared in the following procedure:

i. Pebbles and plant roots were separated from the samples, then all samples were weighed and dried in an oven at a temperature of 110 ^{0}C for 10 hrs., afterword re-weighed until constant weight achieved.

ii. All sample was crushed, homogenized, sieved through a 2 mm mesh sieve.

iii. The final step was to weigh the sieved samples, packing in specific geometrical containers (100, 1000 ml capacity)

iv. Carefully sealed it and stored for 4 weeks to reach secular equilibrium between ^{226}Ra and its decay products (IAEA, 1989, 2019).

v. Preparation of the selected 79 samples to be mechanically analysed to know silt, clay and sand fractions, preparation of the selected samples to be analysed by X-Ray diffraction to identify major and minor minerals.

3.4.2. Gulf Water samples Preparation

We took a liter of Gulf water and filled it in Marinelli-type beakers, then closed and carefully sealed the container well and stored it for 28 days to reach secular equilibrium between ^{226}Ra and its decay products (IAEA, 1989, 2019).

Figure 3-4 The Author with the sampling team

Figure 3-5 Vehicle used for sampling collection trips and boat used for transportation to islands

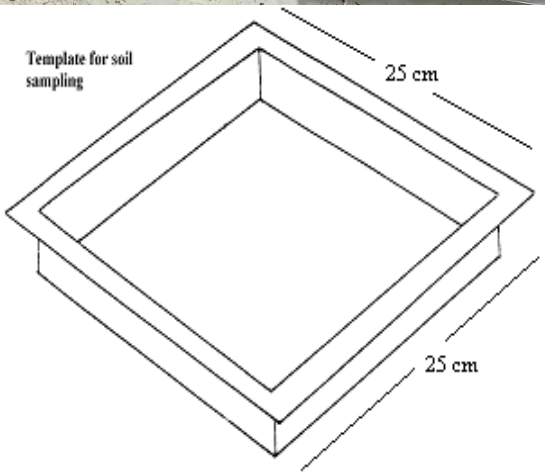

Figure 3-6 Sampling tools include a template used to collect soil and sediments and containers used to collect gulf water.

Table 3-1 *The coordination of the collected samples*

Sample ID	E	N	Sample ID	E	N
1	51.59889	24.26972	41	55.13056	25.07583
2	51.59694	24.38	42	55.19389	25.14667
3	51.65444	24.32611	43	55.23167	25.19389
4	51.74639	24.28806	44	55.35	25.32528
5	51.77806	24.11583	45	55.35944	25.33556
6	51.78083	24.05278	46	55.42139	25.39417
7	51.84028	23.98306	47	55.43694	25.41556
8	52.03	23.98861	48	55.47444	25.45278
9	52.24444	23.97306	49	55.50056	25.48667
10	52.42694	24.05694	50	55.57194	25.59333
11	52.44056	24.12194	51	55.73833	25.64833
12	53.01	24.16056	52	55.78417	25.70472
13	53.1475	24.16611	53	55.92028	25.77056
14	53.32694	24.11111	54	55.95389	25.81083
15	53.44083	24.12556	55	56.04167	25.935
16	53.48417	24.10389	56	56.08694	26.05
17	53.80722	24.24861	57	56.08111	26.02306
18	53.635	24.15472	58	56.27701	25.61028
19	54.13167	24.32167	59	56.35537	25.36583
20	54.08944	24.2925	60	56.35768	25.14444
21	54.16556	24.3125	61	56.37417	24.98278
22	54.30694	24.46528	62	52.32575	24.52945
23	54.31583	24.45417	63	52.31168	24.43882
24	54.31444	24.46278	64	51.73282	24.58887
25	54.33306	24.47833	65	51.71136	24.58745
26	54.33361	24.46861	66	52.00885	24.21542
27	54.34444	24.47583	67	52.00293	24.22982
28	54.35667	24.51917	68	52.64293	24.32711
29	54.33167	24.48778	69	52.56637	24.32086
30	54.28667	24.45833	70	52.56868	24.7849
31	54.39556	24.53722	71	52.5552	24.78483
32	54.4775	24.585	72	52.40341	24.95571
33	54.64083	24.73083	73	52.95369	24.95369
34	54.705	24.80278	74	53.08068	24.88816
35	54.74861	24.84667	75	53.0827	24.88795
36	54.76417	24.84444	76	54.34139	25.39333
37	54.85556	24.88889	77	54.40556	25.39333
38	54.88917	24.91083	78	52.82167	25.27139
39	54.95889	24.96028	79	52.80306	25.23889
40	55.04556	24.99611	----------	---------	---------

3.5. Mechanical (Grain Size Fractionation) Analysis

Mechanical analysis, organic matter, total carbonate, and pH measurements were carried out to differentiate the inorganic mineral portion of soil into classified grades according to particle size and to determine their relative proportions by weight. (White, 1981):

3.6. X-ray diffraction (XRD)

This technique was used to characterising crystalline materials, it is a non-destructive powerful technique which provides valuable information on structures, phases, preferred crystal texture, and other structural parameters, such as mean grain size, crystallinity, strain, and crystal defects. (Chacha, 2014; Whittig & Allardice, 1986). These measurements were conducted for shore sediments and soil samples.

3.7. Gamma Spectrometry Measurements

Gamma ray spectrometers equipped with High Purity Germanium (HPGe) detector was used in this study. Choosing gamma spectroscopy (HpGe detector) is due to its capability to determine natural and anthropogenic radioactivity in the environment and geological samples qualitatively and quantitatively. Its advantages, as it is a non-destructive technique, has high resolution power (1.9 KeV for the energy 1332 of Co-60) which allow it to identify different nuclides in the same test which give the advantage to analysis many nuclides and to be identified in a single analysis, moreover, there are no need for radiochemical treatment for the sample. This technique is credible and widely recommended globally. The main limitations of this technique are the necessity of cooling the detector using liquid nitrogen to reduce the effect of the natural radiation background on the minimum detection limits. The alternative technique as a non-destructive assay would be the use of a NaI gamma spectrometer, but in spite of its sensitivity, using of NaI gamma spectrometer is not suitable in this case due to its bad resolution which is 7% for the 661.6 keV of Cs-137. Also, using mass spectrometry (ICP-MS) is both an expensive tool and a destructive assay technique. (Knoll, 2010).

3.8. Instruments and Instrumental Setup

Gamma ray spectrometers are equipped with high pure germanium detector, which consists of: A hyper pure germanium coaxial detector of a vertical configuration with a relative photo peak efficiency of 40% at the 1332.5keV transition line of ^{60}Co, (Figure 3-7). The detector

is mounted on a 30 litres liquid nitrogen, surrounded by a lead shield which is internally surrounded by copper and cadmium layers against x-ray. The preamplifier is coupled to the detector and connected to the germanium crystal, and the components are kept at liquid nitrogen temperature (77 ^{0}K) to reduce detector noises which are caused by the leakage current generated by the charge carriers at the room temperature. (Canberra, Model GC4020).

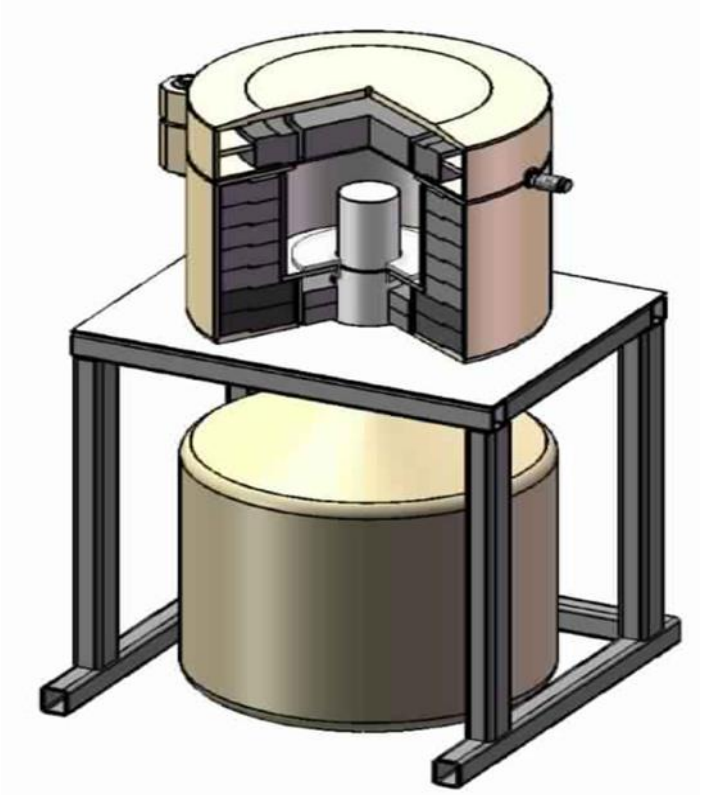

Figure 3-7 HPGe detector with nitrogen Dewar and its lead shield

3.9. Energy Calibration and Peak Identification

A calibration for the spectrometer was conducted using a standard gamma-emitting point sources; ^{137}Cs (661.6keV), ^{60}Co (1173.2 and 1332.5keV) to derive a relationship between channels and the corresponding gamma-ray energies in the spectrum (Gilmore, 2008; Knoll, 2010).

3.10. Efficiency Calibration of HPGe Detector

Efficiency calibration of the detector was conducted in the range from 186keV to 2450keV, it is two stages process; first stage was to use a ^{226}Ra point source to find the relative efficiency curve of the detector, Table 3-2, applying the most intensive gamma rays of ^{226}Ra in equilibrium with its daughters. The relative intensities of the photo peaks corresponding

to these gamma ray lines were measured by the detector and calculated. The photopeak relative efficiency was obtained by dividing the relative intensity of the photo-peak with energy (E) on the reference relative intensity of the same photo-peak applying the following equation:

$$\varepsilon_{(E)} = I_M (E) / I_R (E) \qquad \textbf{Equation 3- 1}$$

Where: $\varepsilon_{(E)}$ is the relative efficiency at energy (E), I_M is the relative intensity measured by the detector for the photopeak with energy (E), and I_R is the reference relative intensity of the same photopeak (Farouk & Al-Soraya, 1982).

Table 3-2 Relative Intensities of γ-Rays from ^{226}Ra radionuclide with its Short-Lived Gamma Emitting Daughters.

No.	Isotope	γ-ray energy (keV)	Relative intensities
1	Ra-226	186.18	9.07 ± 0.14
2	Pb-214	241.2	16.53 ± 0.31
3	Pb-214	258.85	1.72 ± 0.04
4	Pb-214	295.22	42.52 ± 0.59
5	Pb-214	351.99	81.29 ± 0.81
6	Pb-214	545.77	0.63 ± 0.02
7	Bi-214	480.50	0.68 ± 0.02
8	Pb-214	487.25	0.83 ± 0.03
9	Pb-214	609.31	100.00
10	Bi-214	665.45	2.87 ± 0.06
11	Bi-214	703.11	0.82 ± 0.03
12	Bi-214	768.36	10.64 ± 0.03
13	Bi-214	806.17	2.49 ± 0.60
14	Pb-214	934.06	6.54 ± 0.13
15	Pb-214	934.06	6.54 ± 0.13
16	Bi-214	1120.29	33.52 ± 0.42
17	Bi-214	1155.19	3.65 ± 0.07
18	Bi-214	1238.11	13.25 ± 0.22
19	Bi-214	1280.96	3.22 ± 0.06
20	Bi-214	1509.23	4.77 ± 0.099
21	Bi-214	1583.22	1.57 ± 0.03
22	Bi-214	1729.60	6.56 ± 0.12
23	Bi-214	1764.50	34.91 ± 0.41

24	Bi-214	1847.42	4.59 ± 0.09
25	Bi-214	2118.50	2.51 ± 0.05
26	Bi-214	2204.21	10.66 ± 0.20
27	Bi-214	2293.36	0.67 ± 0.02

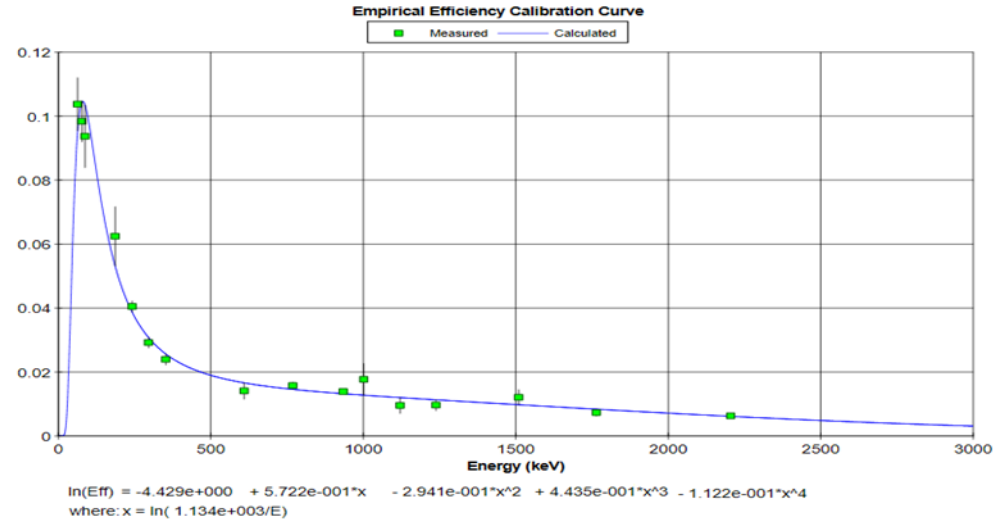

Figure 3-8 Relative Efficiency of HPGe Detector using ^{226}Ra and its Daughters

The relative efficiency curve of the detector was made of 17 different energy values covering the energy range from 186keV to 2450keV. The relative efficiency curve was obtained for two different positions. First, the source was placed in a coaxial position at 15 cm distance from the top surface of the detector. Second, the source was put at the same distance from the detector in a lateral position. The efficiency curve was plotted for both source positions and it was found that the two curves (to a good approximation) coincide in the energy range between 240keV and 2450keV. A slight difference was found at energies less than 240keV. Using both results, an averaging curve (sixth order polynomial fitting) was made, as shown in Figure 3.6. The relative efficiency of the detector corresponding to any photopeak energy can be then obtained using this mean efficiency curve (El-Tahawy *et al*., 1992).

In the second stage of the efficiency calibration of the detector, the mean relative efficiency curve of the detector was normalized to an absolute efficiency Figure 3-8. The normalization has been done using standard solutions of Potassium Chloride (KCl). The radionuclide Potassium-40, in the naturally occurring potassium, is perhaps the most widely used "standardized" low level source for beta-particle and gamma ray emitters. Naturally potassium, containing 0.0118 % of potassium-40, has a specific activity of approximately 850 pCi/g (31.45 Bq/g). Pure KCl is an excellent low-level reference source in many respects: environmental low-level specific activity, wide availability at high purity and relatively simple branching decay. KCl has been used as a low-level standard source for

efficiency calibration of gamma ray spectrometers used for measuring large volumes of low specific activity materials. The normalization was done using different concentrations of KCl for each geometrical configuration. The used concentrations were 16 g/l, 32 g/l, 64 g/l, and 128 g/l, which correspond to 261.8 Bq/l, 532.6 Bq/l, 1047.2 Bq/l, and 2094.4 Bq/l respectively. Using these concentrations and the corresponding counting rates, a normalizing factor for each measuring geometry was then calculated. The normalizing factor for any radionuclide can be calculated relatively to the potassium chloride solution normalizing factor using the following equation (El-Tahawy *et al*., 1992):

$$N.F(Y) = \frac{R.E(1460keV) \times B.R.(^{40}K)}{R.E(Y) \times B.R.(Y)} \times N.F(^{40}K) \qquad \textbf{Equation 3-2}$$

Where: N.F. (Y): the normalizing factor for (Y) radionuclide, R.E. (1460): the relative efficiency of ^{40}K, R.E. (Y): the relative efficiency of radionuclide (Y), P.D. (K):the percentage of photon per disintegration of ^{40}K, P.D. (Y): the percentage of photon per disintegration of (Y) radionuclide, N.F. (^{40}K): the normalizing factor of ^{40}K. It is calculated as N.F. (^{40}K) = weight of KCl × 16.3/ count rate of ^{40}K.

The gamma transitions used for activity calculations of ^{40}K and ^{137}Cs are 1460keV and 661.6keV respectively. For the ^{238}U series they are 351.9keV (^{214}Pb), 609.3keV (^{214}Bi), 1120.3keV (^{214}Bi) and 1764.5keV (^{214}Bi). For the ^{232}Th series they are 338.4keV (^{228}Ac), 583keV (^{208}Tl), 911.1keV (^{228}Ac) and 968.9keV (^{228}Ac).

The calculated activity concentrations were corrected for the sample density. Calculation of ^{226}Ra and ^{232}Th, four and five peaks were used respectively. For each peak, the activity was separately calculated in order to compute the mean activity. Conducting such procedure insure more accurate results with a minimum error (El-Tahawy *et al*. 1992).

3.11. Quality Assurance & Validation

Aiming high level of precision and consistency in the radioactivity measurements a set of quality policies and objectives were applied. The planning, sampling, analyses, reporting and uncertainty of the results is a chain. There are errors in all parts of this chain, and the goal of Quality Assurance and Quality Control (QAQC) is to be able to identify, measure and control these errors. (IAEA, 2004b).

During the radiochemical analyses, a Quality Control (QC) policy were applied to assure that the analyses remain within the required limits of precision and accuracy and the determination is under control. Four types of QC samples were analysed: instrument calibration standards, blank samples, spiked samples, and replicate samples. The quality control measurements include periodic calibrations of counting instruments using traceable standard and routine measurements of instrument backgrounds. Instruments and methods are tested using check sources and spike additions of known quantities of radionuclides, then regular analysis of duplicate samples was carried out. Preparation of blank samples "reagent blanks" starting with de-ionized water or an empty sample container, adding appropriate reagents to the sample in the proper sequence, the normal steps involved in the analysis are followed., ideally, the blank samples should be the same matrix as the routine sample. Preparation of spiked samples is achieved by adding a known amount of the radionuclide we need to measure to blank samples or to samples that have been analysed to obtain a matrix with a known activity. Duplicate samples usually consist of two or more homogeneous solid and liquid portions. Individual samples that are measured by non-destructive techniques, such as γ-ray spectrometry, could be measured more than one time to obtain confirmation of the data (IAEA 2004b). The QAQC system applied in this thesis listed below.

3.11.1. Method Blanks

They are an analysis-free matrix to which all reagents are added in the same volumes and analysed in the same manner as the corresponding samples.

3.11.2. Matrix Spiked Samples

These samples are used to assess the accuracy of analysis and designed to provide information about the effect of the sample matrix on the analytical technique.

3.11.3. Validation through Reference Materials

Standard reference materials are analysed by applying the same methods of analyses to assess the chemical recovery and precision of the methods. Quality assurance procedures are independent tests performed to provide confidence in the prepared samples, standard reference materials samples, samples preparation and the gamma counting system. Generally, the quality assurance program involves (ISO 17025, 2005):

i. Soil and water sampling.

ii. Preparation of different samples for gamma measurements.
iii. Efficiency calibration of germanium detectors for liquid and solid samples.
iv. Background evaluation in the gamma measurements room.
v. Validation of the performance of methods using standard reference materials.
vi. Assessment of the accuracy of results by analysing a blind unknown sample using a laboratory inter-comparison program with an external partner or agency.

3.12. Validation of Method

Equipment status is checked routinely by measuring background, blanks, and standards. Usually, these results give the first indication of analytical difficulties. Analytical control samples often constitute about 10-15% of the total sample's radioactivity. The quality control measurements include periodic calibrations of counting instruments using traceable standard and routine measurements of instrument backgrounds. Instruments and methods are tested using check sources and spike additions of known quantities of radionuclides, followed by regular analysis of duplicate samples (Thompson *et al*., 2002).

3.13. Validation Techniques

The validation techniques include one of, or a combination of methods as explained below:

i. Calibration with reference standards or materials.
ii. To do Comparison of results in this method achieved with other methods.
iii. To do inter-laboratory comparisons.
iv. Systematic assessment can be conducted for the factors influencing the result.
v. Assessment of the uncertainty of the results based on scientific understanding of the theoretical principles of the method and practical experience, see Figure 3.8 (Thompson *et al*., 2002).

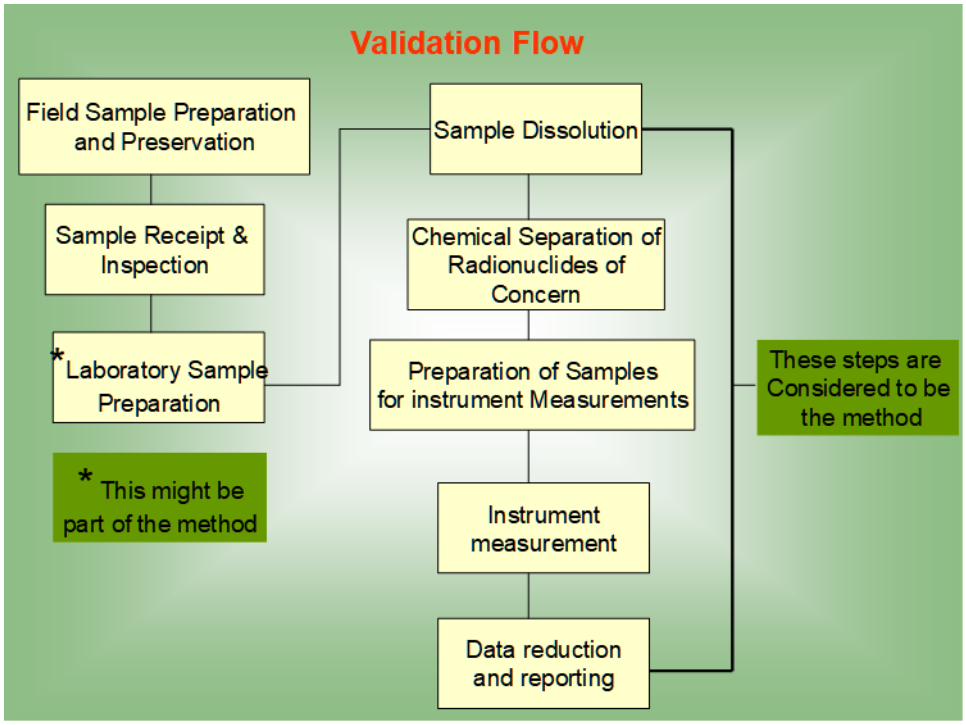

Figure 3-9 Sample preparation validation flow chart

3.14. Sample Container

Measuring gamma radioactivity in soils requires sample containers that are suited to gamma spectrometry. These containers should have the following characteristics:

i. Be made of materials with low absorption of gamma radiation;
ii. Have volumes adapted to the shape of the detector for maximum efficiency;
iii. Be watertight and not react with the sample constituents;
iv. Have a wide-necked, airtight opening to facilitate filling;
v. Be unbreakable.

To verify easily that the content of the container conforms to the standard counting geometry, a transparent container with a mark to check the filling can be selected (IAEA, 2004b).

3.15. Packaging of Samples for Measuring Purposes

The soil samples packaged for gamma spectrometry measurements are usually dried, crushed, and homogenized in accordance with ISO 18589-2. The procedure shall be carried out as follows (IAEA, 2004a).

i. Choose the container that is best suited to the volume of the sample so as to measure as much material as possible. To decrease self-absorption effects, the height of the contents should be minimized.

ii. Fill the container to the level of the volume mark. It is recommended to use a mechanical filling device (for example, a vibrating table) to pack the sample to avoid any future losses in volume.

iii. Note the sample mass. This information is useful when using the measurements to express the result as specific activity and when carrying out self-absorption corrections.

iv. Visually check the upper level of the sample and make sure that it is horizontal before measuring. Where applicable, add more material to the sample until the mark has been reached and adjust the noted sample mass accordingly.

v. Hermetically seal the container if volatile or natural radionuclides are being measured.

vi. Clean the outside of the container to remove potential contamination due to the filling process.

If measurements are required quickly, the processing method described in ISO 18589-2 can be ignored. This shall be mentioned in the test report and the results cannot be expressed in Becquerels per kilogram (Bq/kg) of dry soil. When measuring ^{222}Rn via decay products of ^{226}Ra, the sealed container shall be stored long enough to allow radioactive equilibrium to be reached (IAEA, 2004a).

3.16. Laboratory Background Level

There are isotopes of the decay chain of the rare gas Radon, whose emanation from the materials surrounding the measuring instruments depends on various physical parameters. Thus, large fluctuations in the concentration of radon and of the decay products can occur in room air and in the air of the detector shielding. This is a particular problem in basements of old buildings with defective floors. The background of the measuring instruments shall be kept as low as possible and, in particular, as stable as possible by appropriate measures. This includes vacuuming the shielding and removing the dust by filtration. Frequent measurements of the background level permit the verification of its stability. This is necessary because the peaks of the background spectrum shall be subtracted from those of a sample spectrum (IAEA, 2004b; Knoll, 2010).

3.17. Background Evaluation in the Gamma Counting Room

For the purpose of assuring measuring and analysis it should be review all of the following steps before measuring (IAEA, 2004b):

i. The presence of radioactive sources and samples in the counting room.
ii. The shielding system.
iii. The counting times.

3.18. Energy Calibration

Energy calibration is carried out using sources of a radionuclide with different emission lines (for example ^{152}Eu) or sources containing a mixture of several radionuclides. This calibration allows the establishment of the relationship between the channel numbers of the analyser and the known energy of the photons. Generally, this task is carried out with appropriate software, which uses the standard spectra to automatically convert the channel scale of the multi-channel analyser into a photon energy scale and to record the useful information necessary for future analyses. By using the energy calibration spectra, the full-width at half the maximum of the full-energy peaks can be determined as a function of the gamma energy. This information is usually required by the spectrometry analysis software (Knoll, 2010).

3.19. Efficiency Calibration

Efficiency calibration is carried out using a radionuclide source having different emission lines or a mixed-radionuclide source. This calibration allows the establishment of the detection efficiency of the detector as a function of the energy of the radiation. When using a radionuclide source with different emission lines for calibration, summation effects or coincidence losses should be considered. In general, efficiency calibration may include (Knoll, 2010; Taylor & Opperman, 1998):

i. Check the following parameters: Resolution – Peak energy.
ii. The use of standards and reference materials.
iii. The direct comparison method.
iv. The efficiency calibration curve method.
v. Evaluation of the gamma spectrum.

3.20. Measurements of and Corrections for Natural Radionuclides

If activities of natural radionuclides in the soil are being measured, the areas of full-energy peaks used for evaluating their activities shall be corrected for the background contribution of those same radionuclides inside the detector shielding, taking into account potential differences of the duration of the sample and background measurements. The gamma ray of the radionuclides in the background and/or of natural radionuclides inside the sample can also interfere with measurements of artificial radionuclides and can require appropriate corrections (Taylor & Opperman, 1998).

3.21. Test Report

The test report shall conform to ISO 17025 requirements and shall contain the reference to the ISO 18589, Identification of the sample and, units in which the results are expressed. (ISO 17025, 2005; Taylor & Opperman, 1998).

Chapter 4 Results and Discussion

4.1. Introduction

This study is very important for the United Arab Emirates (UAE) as a baseline radioactivity map before the commercial operation of Barakah nuclear power plant which is located at the UAE`s coast, as shown in Figure 4-1. This plant will be cooled by the Arabian Gulf water to produces 5.6 GWe. The measurements and analyses carried out in this work are considered as pre-operational monitoring to evaluate and assess the environmental impact of the plant operation.

Figure 4-1 Barakah nuclear power plant located at the UAE`s coast (Google Map)

Public health protection is important and in particular with regards to assessing the release of radioactivity to the environment especially when it enters the food chain (IAEA, 1989). Environmental radioactivity control in exposure pathways such as air, water and soil, is the key for determining collective exposure doses and developing effective radiological protection schemes (Gomez E. et al, 1994).

Gathering information on radionuclides in the hydrosphere is an important issue for a few reasons, mainly the need for understanding and assessing the fate of these radionuclides and their effect on the environment and human health which in turn will be the basis knowledge for assessing the impact of future releases especially if unplanned. Unplanned activities include potential accidents with the release of radionuclides from facilities such as nuclear power plants or nuclear waste disposal sites, or from the shipping of nuclear fuel or nuclear

waste. In addition, radionuclides can be used as powerful tracers that provide essential insights into a variety of oceanic processes. Worldwide on-land monitoring of radionuclides can be helpful in estimating the global fallout in the world ocean (IAEA, 2005).

This study is sought to obtain results that contribute to the radiological monitoring and evaluation of natural radionuclides $^{238}U(^{226}Ra)$, ^{232}Th, ^{40}K and the anthropogenic ^{137}Cs present in the Arabian Gulf coastline of the United Arab of Emirates and some Islands. The specific activities of $^{238}U(^{226}Ra)$, ^{232}Th, ^{40}K and ^{137}Cs in the collected samples from soil, sediment and Gulf water were measured by gamma spectrometers based on high purity germanium detectors (HpGe). The reasons for the choice of the radionuclides investigated are their significant contribution to the dose commitment and as base line map.

Because of the long-distance of the cost of United Arab of Emirates, the samples locations were divided to the three different regions:

i. Abu Dhabi Emirate Region,
ii. Dubai and the Northern Emirates Region and
iii. Islands in the Arabian Gulf.

The results of the soil and sediment mechanical analysis and chemical analysis of water samples will be represented for the three regions collectively.

Ranges given in the text are simply the minimum and maximum values of the measured specific activity. The ± values in the tables were calculated based on the reported errors in the count rate / net area at each specific energy for specific radionuclide as given by the Maestro (Gamma Vision) software of the ORTEC Gamma spectrometer

4.2. Mechanical and Chemical Analysis of Soil Samples in the three Regions

The mechanical (grain size) analysis of soil samples is given in Appendix A. The results indicate that the size nature of the soil is sand grading. Using statistical approach carried out on the sand size grading data, the results show the following major observations;

i. Most of the sand sizes were found between the size 0.5 – 0.25mm and 0.25 – 0.125mm.
ii. These sand sizes (0.5– 0.25mm and 0.25 – 0.125mm), represent approximately 65% of the weight of the samples measured.

iii. The sand size 1- 0.5 mm represents approximately 17.3% of the samples weight.

iv. The sand size: 0.0125 – 0.063 mm represents approximately 12.9% of the samples weight.

v. The sand size: 2 – 1 mm represents approximately 4.8% of the samples weight.

This analysis gives rise to that the soil is moderately fine but not coarse, hence, it could easily transport and precipitate by seawater currents, but not to too far distances. Also, as mentioned before, the noticeable difference between the sand grain size and that of soil, as a result of the differences in textural properties of these environmental components, leads to the slight variation in the radioactivity content in soil samples that may appear in measuring data.

The chemical analysis of selected soil samples is presented in Appendix B. The results give a picture of the chemical nature of the soil and how this nature can affect the transportation and precipitation the radionuclides in the soil. The results indicate that, in general, as the alkalinity increases (causing decreasing pH values) with increasing calcium carbonate percentage, the soil media become more neutral, and the electric conductivity increases when increasing neutralization. So, increasing alkalinity leads to decreasing radionuclides precipitation and hinders the cation exchange between their natural compounds and the seawater. On the other hand, decreasing alkalinity leads to that water becomes more neutral unless it would become more acidic and enhance electric conductivity and hence increases the rate of cation exchange and leads to increase the radionuclides transportation and precipitation to the soil.

The calcite ($CaCO_3$) mineralogy (texture) has affinity towards radionuclides concentration, especially uranium. Calcium Carbonate CaCo3 is the major constituent of sedimentary rock such as limestone. Limestone, dolomites and other sedimentary carbonate rocks, it is considered to be the least uraniferous structure, the Uranium concentration in such structure range from zero to 4ppm, however, this structure prefers uranium in specific oxidation state. Therefore, defining the geological formations is an important means of controlling uranium mobility in the environment. (Saleh and Yun, 2017)

4.3. Mechanical and Chemical Analysis of Sediment Samples in the Three Regions

The mechanical (grain size fractionation) analysis of sediment samples is given in (Appendix C). The results of the measurements of the grain size of sediment is sand and its grading using statistical approach, indicate the following major points:

i. Most of the sand sizes were found between the size 1-0.5 mm ,0.5 – 0.25 mm and 0.25 – 0.125 mm.
ii. These sand sizes (1-0.5 mm, 0.5–0.25 mm and 0.25–0.125 mm), represent approximately 75% of the sediment samples weight measured.
iii. The sand size 1- 0.5 mm represents approximately 17.5% of the samples weight.
iv. The sand size: 0.0125–0.063 mm represents approximately 2.2% of the samples weight.
v. The sand size: 2– 1 mm represents approximately 5.3 % of the samples weight.

This analysis gives rise to that the sediment is moderately coarse more than soil. Hence the sediment not easily transports and precipitate by seawater currents but as mentioned before as this gap between the sand sizes of the samples and also difference in sediment texture, as a result of the differences in textural properties of sediment samples. This leads to the conclusion that the more variation in the radioactivity content in sediment samples may appear in measuring data.

The chemical analysis of sediment samples is presented in (Appendix D). The results give a picture about the chemical nature of the sediments, especially in presence of Gulf seawater media and how the change in pH values can affect the transportation and precipitation the radionuclides in the sediment. The results indicate that, in general, as the alkalinity increase (causing a decrease in pH values) with increasing calcium carbonate percentage, the sediment media become more neutral, and the electric conductivity increases when increasing neutralization. This may be attributed to decreasing pH of the media which leads to increase electric conductivity and increase ionic exchange in water media and hence the rate of dissolution and deposition of these ions in the sediment. This effect is repeated alternatively, this leads to continuous dissolution and deposition of different metal ions and its deposition and dissolution in sediment.

This process also affected by the change in aquatic media of the seawater of the Gulf and with water currents and directions. Also, industrial activities, like oil and gas industries in deep water and water effluents produced from electric power stations and other activities may be a direct reason to increase the activity concentrations values of natural radionuclides.

This explanation may be clear when comparing the chemical analysis results of some sediment and soil samples as shown in (Appendix E). It was observed that most of the electric conductivity values in sediment were less than its values in soil samples, which means that the content of free ions in sediments is much lower than free ion concentrations in soil. This is not a major observation and at the same time the opposite behaviour was observed. In some locations in sediment there are a higher percent of ions higher than soil and vice versa. This behaviour gives some explanation about the different concentrations of activity values of radionuclides. But its contradiction to the mean and the maximum activity values of different radionuclide ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs needs for more investigation. This will be a good point for more studies in the future.

4.4. Results and Discussion of Abu Dhabi Emirate Samples

Measurements of terrestrial radionuclides ^{238}U(^{226}Ra), ^{232}Th, ^{40}K and the anthropogenic ^{137}Cs have been carried out for the collected soil samples using gamma ray spectrometry as explained in the experimental work. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs ± 1σ uncertainties, in the coastal area samples (Soil, Shore sediment and Seawater) of Abu Dhabi region are presented in the following sections. The activity values are given in Bq/kg on a dry weight basis.

4.4.1. Soil Samples Results

The activity concentrations of ^{238}U(^{226}Ra), ^{232}Th, ^{40}K and ^{137}Cs ± 1σ uncertainties, in the Soil samples of the coastal area of Abu Dhabi Emirate are presented in Table 4.6. The activity values are given in Bq/kg on a dry weight basis.

4.4.1.1. Radium-226 and Thorium-232 Activity Results

Table 4.6 represent the activity concentrations values of both ^{226}Ra and ^{232}Th in soil samples collected from Abu Dhabi Emirate (the connected lines in all the figures were carried out to clarify a variation of activity with the sites). The results indicate that the maximum concentrations for ^{226}Ra and ^{232}Th were 55.05 and 18.47 Bq/kg whereas the minimum

concentrations were 2.79 and 0.57 Bq/kg respectively. The mean concentrations values of both ^{226}Ra and ^{232}Th were 16.68 and 4.09 Bq/kg respectively. These results show that the mean activity concentration values of the naturally occurring radionuclides in the collected soil samples from Abu Dhabi Emirate are lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000). Also, the maximum activity concentrations 49.56 and 55.05 Bq/kg of ^{226}Ra were observed for sites S4 and S6 respectively, are higher than the world mean activity for ^{226}Ra. So, these sites (S4) and (S6) are recommended for further investigation in the future.

The measurements of the activity concentrations of natural radioactivity in soil samples can be influenced by the fractions of the grain size and mineralogy of the samples. These values for radium and thorium content in soils are generally lower than those reported in soils from Egypt (Sroor *et al*., 2001), Kuwait (Bou-Rabee, 1997), Oman (Goddard, 2002), (Saleh, 2012) and Saudi Arabia (Alaamer, 2008; Al-Ghorabie, 2005; El-Aydarous, 2007). The presence of relatively higher values of ^{226}Ra in some locations represents samples (S4 and S6) may be attributed to the differences in textural properties of these soils.

Table 4-1 Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and ^{137}Cs in soil samples in Abu Dhabi

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S1	7.20	±	0.36	2.19	±	0.10	95.00	±	4.75	0.69	±	0.03
S2	10.58	±	0.52	2.40	±	0.12	78.24	±	3.91	0.60	±	0.03
S3	18.2	±	0.91	5.25	±	0.26	214.61	±	10.7	1.46	±	0.07
S4	49.56	±	2.47	3.60	±	0.18	83.52	±	4.20	3.11	±	0.15
S5	18.22	±	0.91	4.11	±	0.20	109.07	±	5.60	0.14	±	0.01
S6	55.05	±	2.75	18.47	±	0.92	213.06	±	10.6	2.75	±	0.13
S7	18.20	±	0.91	4.11	±	0.20	109.10	±	5.45	0.27	±	0.01
S8	18.10	±	0.90	5.25	±	0.26	214.61	±	10.7	0.36	±	0.02
S9	6.74	±	0.37	1.33	±	0.06	75.54	±	4.00	0.06	±	0.01
S10	7.53	±	0.37	3.13	±	0.15	143.06	±	7.15	3.77	±	0.18
S11	6.86	±	0.34	3.84	±	0.19	149.0	±	7.45	0.83	±	0.04
S12	5.61	±	0.28	5.50	±	0.27	128.44	±	6.42	0.63	±	0.03
S13	15.90	±	0.79	10.4	±	0.52	410.75	±	20.5	0.24	±	0.01
S14	22.31	±	1.11	4.62	±	0.23	139.08	±	7.00	0.85	±	0.04
S15	29.09	±	1.45	4.16	±	0.20	148.22	±	7.41	0.42	±	0.02
S16	22.07	±	1.10	1.72	±	0.08	108.11	±	5.40	0.13	±	0.01
S17	17.19	±	0.85	1.98	±	0.09	55.93	±	2.80	0.86	±	0.04
S18	22.60	±	1.13	2.26	±	0.11	71.83	±	3.60	1.31	±	0.06
S19	13.50	±	0.65	3.63	±	0.18	46.87	±	2.34	0.44	±	0.02
S20	17.80	±	0.89	14.50	±	0.72	531.08	±	26.5	0.28	±	0.01
S21	16.54	±	0.82	5.00	±	0.25	154.65	±	7.73	0.22	±	0.01
S22	22.30	±	1.11	4.62	±	0.21	139.08	±	7.00	0.84	±	0.04
S23	29.10	±	1.45	4.16	±	0.20	148.22	±	7.41	0.42	±	0.02

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S24	22.06	±	1.10	2.92	±	0.14	108.11	±	5.40	0.13	±	0.01
S25	17.16	±	0.85	3.55	±	0.17	55.92	±	3.00	0.85	±	0.04
S26	22.60	±	1.13	2.26	±	0.11	71.83	±	3.60	1.31	±	0.06
S27	13.50	±	0.67	3.62	±	0.18	46.86	±	2.34	0.44	±	0.02
S28	27.11	±	1.35	4.55	±	0.22	152.28	±	7.61	1.92	±	0.09
S29	22.60	±	1.13	3.97	±	0.19	133.28	±	6.70	0.96	±	0.04
S30	4.05	±	0.22	2.72	±	0.13	30.16	±	1.50	0.19	±	0.01
S31	11.66	±	0.58	6.83	±	0.34	130.14	±	6.50	1.37	±	0.06
S32	16.06	±	0.80	3.00	±	0.15	76.71	±	3.83	1.31	±	0.06
S33	13.60	±	0.68	2.57	±	0.18	96.22	±	4.81	0.60	±	0.03
S34	16.15	±	0.80	5.32	±	0.26	84.50	±	4.22	0.76	±	0.03
S35	15.29	±	0.76	5.06	±	0.25	23.76	±	1.20	0.21	±	0.01
S36	10.09	±	0.50	2.23	±	0.11	42.58	±	2.13	0.24	±	0.01
S37	6.69	±	0.33	2.03	±	0.10	36.00	±	1.80	0.19	±	0.01
S38	6.09	±	0.30	1.38	±	0.06	17.50	±	0.87	0.05	±	0.01
S39	5.65	±	0.28	1.61	±	0.08	16.48	±	0.82	0.15	±	0.01
S40	9.87	±	0.49	0.91	±	0.04	53.23	±	2.66	0.80	±	0.04
S41	7.68	±	0.38	0.75	±	0.03	18.29	±	0.91	0.04	±	0.01
S42	2.79	±	0.13	0.57	±	0.02	16.12	±	0.81	0.71	±	0.03
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**
Mean	**16.68**		**---**	**4.09**		**---**	**113.74**		**---**	**0.78**		**---**

However, the slight variation in the radioactivity content in soil samples may also be explained by the variations in soil type, formation, and transport processes due to changes in water currents in the Gulf and along water near the shore for a long period of time (Baeza *et al*, 1995; Belivermis *et al*, 2010).

4.4.1.2. Potasium-40 Activity Results

The activity concentrations of ^{40}K in the soil samples collected from Abu Dhabi Emirate represent in Table 4.6. The results indicate that the maximum concentration of ^{40}K was 531.08 Bq/kg and the minimum concentration is 16.12 Bq/kg with an mean value of 113.74 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected soil samples from Abu Dhabi Emirate are lower than the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000). Potassium is a part of the clay components (Shale) and the activity concentrations of ^{40}K can be affected by the degree of finance of the aggregate and the pH values of the Gulf water hence the relative solubility of the natural potassium in the soil. Increasing neutralization of the soil leads to increase the electric conductivity and hence increase the rate of dissolution of potassium in the soil media, this

process leads to increase concentration of potassium in soil and increase its activity values. The results indicate that location represent samples S13 and S20 have the highest activity values; 410.75 and 531.08 Bq/kg respectively. These values considered being higher than the world mean of ^{40}K activity values 400 Bq/kg (UNSCEAR 2000). So, it is recommended that these locations would subject for continuous follow up and assessment of the potassium ^{40}K activity in the future.

4.4.1.3. Cesium-137 Activity Results

Caesium is the most electropositive and the most alkaline element among alkali metals with an atomic mass ranging between 125 to 145 with only ^{133}Cs is the stable isotope and is natural. Caesium has two well-known radioactive isotopes ^{134}Cs and ^{137}Cs, and the latter is only obtainable from a nuclear fission. The main sources of ^{137}Cs present in the environment are:

i. Release from nuclear accidents such a Chernobyl and Fukshima nuclear reactors in 1986 and 2011 respectively
ii. Atmospheric nuclear weapons tests carried out during the period from the late 1950s to 1970s.
iii. Local releases from nuclear reactor and waste reprocessing plants (IAEA, 2014).

Due to it's quick and fast adsorption by fine soil particles and also it's accumulation at or near soil particles surface, ^{137}Cs tracking can be provide a very effective means of tracing rates and patterns of erosion and deposition within agricultural landscapes or of course shores nearby the Gulfs.

To assess the redistribution of ^{137}Cs, a comparison is made between two samples at a specified site, one taken as a specimen and the other which is a reference is used as the cumulative atmospheric fallout input at the site, taking due account of the different behaviour of the surrounding environment. Due to the fact that long term measurements of atmospheric fallouts are rare or almost non existing, the reference inventory is usually established by sampling adjacent stable and nearly undisturbed sites. But this was not the case of this investigation and also there was no data available for the investigated area before this study was conducted, so the assessment of ^{137}Cs activity values would be the reference values and in the same time the inventory for any future work in this field in the investigated area in the United Arab of Emirates. Soil erosion and sedimentation rates and patterns known as soil

redistribution data can be taken as an integrated measurement of all effects leading to soil redistribution from the time of the fallout to that of sampling. The absence of the short-lived ^{134}Cs in all the collected samples can be mainly attributed, as previously discussed, nuclear weapons testing and nuclear power plants accidents.

The measured activity concentration values of ^{137}Cs in the analysed soil samples of Abu Dhabi Emirate are represented in Table 4.6. It is clearly appearing that the activity concentrations of ^{137}Cs ranged from 0.04 to 3.77 Bq/kg, with an mean value of 0.78 Bq/kg in the soil samples.

These values are well comparable to those reported in soils from Pakistan (1.6 Bq/kg) (Rafique, 2014), from Palestine (2.8 Bq/kg) (Abu Samreh *et al.*, 2014), and from Suez Gulf, Egypt (0.1 Bq/kg) (Salama *et al*., 2015).

It can be observed that the samples S4, S6 and S10 have much higher ^{137}Cs than that the mean value (0.7 Bq/kg). These three locations would be a reference for any further investigation in the future. The samples S4 and S6 are of higher ^{226}Ra and ^{232}Th activity. The higher activity values of ^{137}Cs (S10 ; 3.77 Bq/kg) may be attributed to the continuous transportation, including erosion and accumulation of the radionuclides in soil by the action of water currents in the Gulf. Also, the pH values and increasing or decreasing alkalinity play another role. This result also revealed that the activity values of ^{137}Cs are a less abundant radioactive element than the other elements in the soil samples in Abu Dhabi Emirate under consideration in this investigation. The results revealed in a clear way what the situation of the inventory and the distributed activity concentrations of ^{137}Cs which is very important as a reference for the future investigation work especially that Barakah NPP is going to be connected into national grid in the very near future; operation license was issued in February 2020.

4.4.1.4. Maximum Activity Concentrations in Abu Dhabi Emirate Samples

Table 4-2 illustrates a concise summary for the results of the maximum activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples respectively. The maximum activity concentrations of ^{226}Ra are found to be 49.56, 55.05 Bq/kg for Sites S4 and S6, of ^{232}Th are 18.47, 14.50 Bq/kg for sites S6 and S20, of ^{40}K are 531.08 Bq/kg for site S20, 410.75 Bq/kg for site S13. The observed activity concentrations for ^{137}Cs are found to be 3.11 and 3.77 Bq/kg for sites S4 and S10. All the locations represent these samples are

recommenced for any further assessment and follow up in the future modernization of the radiological baseline map of the UAE.

Table 4-3 illustrates the comparison between the local mean activity concentration measured in Abu Dhabi Emirate for the natural radioactivity and the world mean.

Table 4-2 The Maximum Activity Concentrations Observed for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in Soil Samples ± 1σ Uncertainties

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S4	49.56	±	2.47	---		---	---		---	3.11	±	0.15
S6	55.05	±	2.75	18.47	±	0.92	---		---			
S10	---		---	---		---	---		---	3.77	±	0.18
S13	---		---	---		---	410.75	±	20.5	---		---
S20	---		---	14.50	±	0.72	531.08	±	26.5	---		---

Table 4-3 The comparison of measured mean activity concentrations observed for ^{226}Ra, ^{232}Th, and ^{40}K and the world mean (UNSCEAR, 2000)

Mean	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
Abu Dhabi Mean	16.68	4.09	113.74
World Mean	35	30	400

4.4.2. Results of Shore Sediment Samples Analysis

The activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs ± 1σ uncertainties, in the shore sediments samples of the coastal area of Abu Dhabi Emirate are presented in Table 4-4.

4.4.2.1. Radium-226 and Thorium-232 Activity Results

The results indicated that the maximum concentrations for ^{226}Ra and ^{232}Th were 25.5 and 10.3 Bq/kg whereas the minimum concentrations were 1.15 and 0.74 Bq/kg respectively. The mean concentrations values of both ^{226}Ra and ^{232}Th are 10.6 and 3.35 Bq/kg respectively indicating that the mean activity concentration values of the naturally occurring radionuclides in the collected shore sediments samples from the coastal area of Abu Dhabi Emirate are much lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000). The highest activity concentration values of ^{226}Ra are represented for both sites SS4, SS8 and SS17 with activity values of 23.78, 25.5 and 24.36 Bq/kg respectively. All these values are lower than the world mean but still close to it 35 Bq/kg, (UNSCEAR, 2000). So, these sites will be recommended for further follow up in the

future. Whereas the result shows that ^{232}Th does not have the same behaviour. The results indicate that the highest concentration values of ^{232}Th are represented for sites SS8, SS23 and SS30 with activity values of 10.3, 8.57, 9.10 Bq/kg respectively, which are much lower than the world mean. The activity concentration values of ^{226}Ra and ^{232}Th are given in in Figure 4.6 in Bq/kg on a dry weight basis.

Some sediment properties such as carbonates and particle size which might have a different effect on the mobilisation of natural radionuclide, can alter radionuclide activities (Shetty et al., 2006). The values obtained for ^{226}Ra and ^{232}Th are fairly low compared to those in coastal marine sediments in other parts of the middle east such as sediments in Egypt: 10.7 and 13.7 Bq/kg respectively (El-Tahawy et al., 1994) , 24.7 Bq/kg and 31.4 respectively (El Mamoney & Khater, 2004), in Oman (11.0-22.0 and 10.0-25.0 Bq/kg respectively (Zare et al., 2012) and In Iran 18.3 and 17.2 Bq/kg respectively (Tari et al., 2013).

4.4.2.2. Potasium-40 Activity Results

The activity concentrations of ^{40}K in the shore sediment samples collected from Abu Dhabi Emirate are represented in Table 4-4. The results indicate that the maximum activity concentration of ^{40}K is 528.76 Bq/kg and the minimum concentration was 0.58 Bq/kg with an mean value of 121.57 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected shore sediment samples from Abu Dhabi Emirate are below the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000). The variation in the activity concentration of ^{40}K content in shore sediments may be attributed to the variation in clay, silt and sand and organic matter percentages along with the shore sediments. Potassium has higher activity concentrations for many reasons; One of these reasons refer to the chemical nature of potassium and its low mass number and chemical reactivity, hence potassium easy to dissolve in water then transport and deposited in soil or sediment more easily than both ^{226}Ra and ^{232}Th. After all, there are three locations represent the samples were observed to attain a maximum activity concentration values of ^{40}K for sites SS8, SS15 and SS16 with 435.18, 528.76 and 437.54 Bq/kg respectively Table 4.4. Activity concentration values in such locations were higher than mean values (UNSCEAR, 2008). Hence this investigation recommends that these locations would be subjected for continuous follow-up and assessment of the potassium ^{40}K activity in the future

Table 4-4 Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in shore sediment Samples ± 1σ uncertainties for Abu Dhabi Emirate

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
SS1	9.22	±	0.46	1.85	±	0.09	128.35	±	6.41	1.01	±	0.05
SS2	12.04	±	0.60	2.33	±	0.11	237.63	±	11.20	0.03	±	0.01
SS3	1.15	±	0.05	1.74	±	0.08	11.61	±	0.58	0.11	±	0.01
SS4	23.78	±	1.18	3.44	±	0.17	73.75	±	3.68	3.26	±	0.16
SS5	8.84	±	0.44	1.64	±	0.08	52.61	±	2.63	0.30	±	0.01
SS6	14.10	±	0.70	5.89	±	0.29	243.15	±	12.15	0.41	±	0.02
SS7	4.88	±	0.24	1.93	±	0.09	78.76	±	3.93	0.24	±	0.01
SS8	25.50	±	1.27	10.3	±	0.51	435.18	±	21.75	1.82	±	0.09
SS9	9.24	±	0.46	6.39	±	0.31	209.59	±	10.47	0.91	±	0.04
SS10	3.75	±	0.18	2.38	±	0.11	83.00	±	4.15	0.05	±	0.01
SS11	4.97	±	0.24	0.74	±	0.03	89.50	±	4.47	0.14	±	0.01
SS12	8.52	±	0.42	3.54	±	0.17	166.59	±	8.32	0.57	±	0.03
SS13	7.79	±	0.38	3.14	±	0.15	181.09	±	9.05	0.57	±	0.02
SS14	12.92	±	0.64	3.03	±	0.15	106.37	±	5.31	0.20	±	0.01
SS15	6.29	±	0.31	3.83	±	0.19	528.76	±	26.43	0.02	±	0.01
SS16	9.87	±	0.49	7.25	±	0.36	437.54	±	21.87	0.61	±	0.03
SS17	24.36	±	1.21	5.49	±	0.27	173.91	±	9.00	0.15	±	0.01
SS18	10.97	±	0.54	3.79	±	0.18	123.27	±	6.16	0.51	±	0.02
SS19	11.35	±	0.56	3.90	±	0.19	149.85	±	7.49	0.32	±	0.01
SS20	14.30	±	0.71	3.92	±	0.19	134.31	±	6.71	0.05	±	0.01
SS21	7.37	±	0.36	3.60	±	0.18	56.16	±	2.80	0.23	±	0.01
SS22	14.49	±	0.72	4.55	±	0.22	141.80	±	7.09	0.42	±	0.02
SS23	15.86	±	0.79	8.57	±	0.42	181.63	±	9.08	0.89	±	0.04
SS24	11.74	±	0.58	4.04	±	0.20	186.98	±	9.34	0.15	±	0.01
SS25	17.19	±	0.85	3.76	±	0.18	140.81	±	7.04	0.16	±	0.01
SS26	5.39	±	0.26	0.88	±	0.04	0.58	±	0.02	0.11	±	0.05
SS27	12.91	±	0.64	2.36	±	0.11	109.54	±	5.47	0.20	±	0.01
SS28	5.76	±	0.28	1.77	±	0.08	31.92	±	1.60	0.84	±	0.04
SS29	11.70	±	0.58	1.82	±	0.09	76.39	±	3.81	0.03	±	0.01
SS30	12.94	±	0.64	9.10	±	0.45	58.82	±	2.94	0.42	±	0.02
SS31	16.58	±	0.82	1.93	±	0.09	53.81	±	2.69	0.26	±	0.01
SS32	17.18	±	0.85	2.31	±	0.11	38.80	±	1.94	0.21	±	0.01
SS33	14.13	±	0.70	3.07	±	0.15	41.51	±	2.07	1.23	±	0.06
SS34	5.35	±	0.26	0.79	±	0.03	23.92	±	1.19	0.02	±	0.004
SS35	6.99	±	0.34	1.08	±	0.05	45.79	±	2.28	0.55	±	0.02
SS36	5.21	±	0.26	1.62	±	0.08	33.59	±	1.67	0.17	±	0.01
SS37	8.11	±	0.40	1.79	±	0.08	11.30	±	0.56	0.24	±	0.01
SS38	4.74	±	0.23	2.14	±	0.10	40.45	±	2.02	0.20	±	0.01
SS39	4.10	±	0.20	1.58	±	0.07	29.78	±	1.48	0.14	±	0.01
SS40	14.20	±	0.71	4.69	±	0.23	115.99	±	5.79	0.64	±	0.03
SS41	6.49	±	0.34	1.29	±	0.06	23.92	±	1.19	0.06	±	0.003
SS42	3.09	±	0.15	1.54	±	0.07	17.72	±	0.88	0.51	±	0.02
Minimum	**1.15**	**±**	**0.05**	**0.74**	**±**	**0.03**	**0.58**	**±**	**0.02**	**0.02**	**±**	**0.01**

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
Maximum	**25.5**	**±**	**1.27**	**10.3**	**±**	**0.51**	**528.76**	**±**	**26.43**	**3.26**	**±**	**0.16**
Mean	**10.6**			**3.35**			**121.75**			**0.45**		

4.4.2.3. Cesium-^{137} Activity Results

Assessment of ^{137}Cs activity concentrations in this study is considered for ascertain if there has been any fallout of ^{137}Cs in the coastal areas and the islands. The results indicated that the presence of ^{137}Cs in the sediment was evident for fallout, its maximum activity is 3.26 Bq/kg and the minimum is 0.02 Bq/kg, with an mean value of 0.45 Bq/kg, as presented in Table 4-4. These values were less than world records, pre Chernobyl, in marine sediments (UNSCEAR, 2008). The passage of nuclear submarine and aircrafts carriers through the Gulf is also considered as source of ^{137}Cs in the environment.

4.4.2.4. Maximum Activity Concentrations in Abu Dhabi Emirate Shore Sediment

Table 4.5 illustrates a concise summary for the results of the maximum activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in shore sediment samples respectively. The maximum activity concentrations of ^{226}Ra are found to be 23.78 and 25.5 Bq/kg for sites SS4 and SS8, of ^{232}Th are 10.3, 8.57 and 9.1 Bq/kg for sites SS8, SS23 and SS30 respectively. Where, the maximum activities of ^{40}K are found to be 435.18, 528.76 and 437.54 Bq/kg for sites SS8, SS15 and SS16. The highest activity concentration of ^{137}Cs is observed to be 3.26 Bq/kg for site SS4. All of samples have activity concentrations for ^{226}Ra and ^{232}Th lower than the world means except that for ^{40}K it is found higher than that mean. Hence all the previous locations represent these samples are recommenced for further assessment and follow up in the future.

Table 4-5 The maximum activity concentrations observed for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in shore sediment samples ± 1σ uncertainties

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
SS4	23.78	±	1.18							3.26	±	0.16
SS8	25.50	±	1.27	10.3	±	0.51	435.18	±	21.75			
SS15							528.76	±	26.43			
SS16							437.54	±	21.87			
SS23				8.57	±	0.42						
SS30				9.10	±	0.45						

4.4.3. Results of Gulf Water Samples Analysis

The activity concentrations of ^{40}K in the Gulf water samples collected from Abu Dhabi Emirate region represented in Table 4-6.

The results indicate that the maximum concentration of ^{40}K is 17.36 Bq/kg and the minimum concentration is 5.37 Bq/kg with an mean value of 11.33 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected Gulf water samples from Abu Dhabi Emirate are too much lower than the world mean value of ^{40}K (UNSCEAR, 2000). This indicates that the transfer of ^{40}K from soil or sediment to Gulf water in Abu Dhabi Emirate is very slow. It should be mentioned that the ^{238}U (^{226}Ra) and ^{232}Th were not observed in the analysed Gulf water samples. They might be lower than the spectrometer lower detection limit. The anthropogenic ^{137}Cs was not also found in the investigated samples.

Table 4-6 Activity concentrations of ^{40}K in seawater in Abu Dhabi Region

Sample Code	Activity (Bq L^{-1})			Sample Code	Activity(Bq L^{-1})		
W1	16.55	±	0.82	W14	6.97	±	0.34
W2	17.36	±	0.86	W15	11.70	±	0.58
W3	12.22	±	0.61	W16	14.00	±	0.70
W4	6.64	±	0.33	W17	15.52	±	0.77
W5	14.17	±	0.70	W18	16.48	±	0.82
W6	10.38	±	0.51	W19	5.37	±	0.26
W7	7.90	±	0.39	W20	11.00	±	0.55
W8	10.70	±	0.53	W21	13.05	±	0.65
W9	17.03	±	0.85	W22	7.07	±	0.35
W10	10.56	±	0.52	W23	10.38	±	0.51
W11	6.0	±	0.30	W24	11.32	±	0.56
W12	6.77	±	0.33	W25	9.79	±	0.48
W13	14.39	±	0.71				
Minimum	**5.37**	**±**	**0.26**				
Maximum	**17.36**	**±**	**0.86**				
Mean	**11.33**						

4.4.4. Correlation Coefficient (r) between ^{226}Ra, ^{232}Th and ^{40}K activities in Abu Dhabi Emirate

The Correlation Coefficient (r) between ^{226}Ra (as a daughter of ^{238}U) and ^{232}Th activity concentrations for soil and shore sediment samples was calculated. Also, correlation for ^{40}K activity concentrations in soil, shore sediment and Gulf water was performed to show if there

is any relationship between these natural radionuclides in transformation and movement due to sea currents in the Gulf and tide waves along the shore.

The natural activity concentrations of ^{226}Ra and ^{232}Th in the Earth's crust are 2.9 and 9.6 ppm, respectively, which corresponds to a specific activity of 36.0 and 39 Bq/kg respectively (UNSCEAR, 2000). The ^{226}Ra/^{232}Th activity ratios in this study for soil samples are in the range from 1.0 to 13.7 with mean value of 4.86. For shore sediment samples, it is found to be in the range from 0.27 to 17.64 with a mean value 3.83.

The correlation between ^{226}Ra and ^{232}Th activity concentrations in the collected soil and shore-sediment samples is depicted in Figures 4.2 and 4.3 respectively. The calculated correlation coefficient in soil samples for ^{226}Ra to ^{232}Th (r) is found to be positive with value of (0.521) Fig 4.2. The positive correlation is quite logical, as both have the same terrestrial origin, however, it is not a significant correlation and that may be attributed to the varieties of sample locations which can influence the chemical and physical properties of the soil.

Similarly, in shore sediment samples, the correlation coefficient (r) of ^{226}Ra/^{232}Th was found to be positive with value of (0.586) Fig 4.3, for which also indicate a non-significant correlation between ^{226}Ra and ^{232}Th. The radioactivity content inshore sediment is affected by many environmental changes in the rocks from which the sediment is formed, these changes can be the atmospheric deposition (dry and wet), seawater flux or currents, and the physical and chemical properties of the sediment (Khater, 1997).

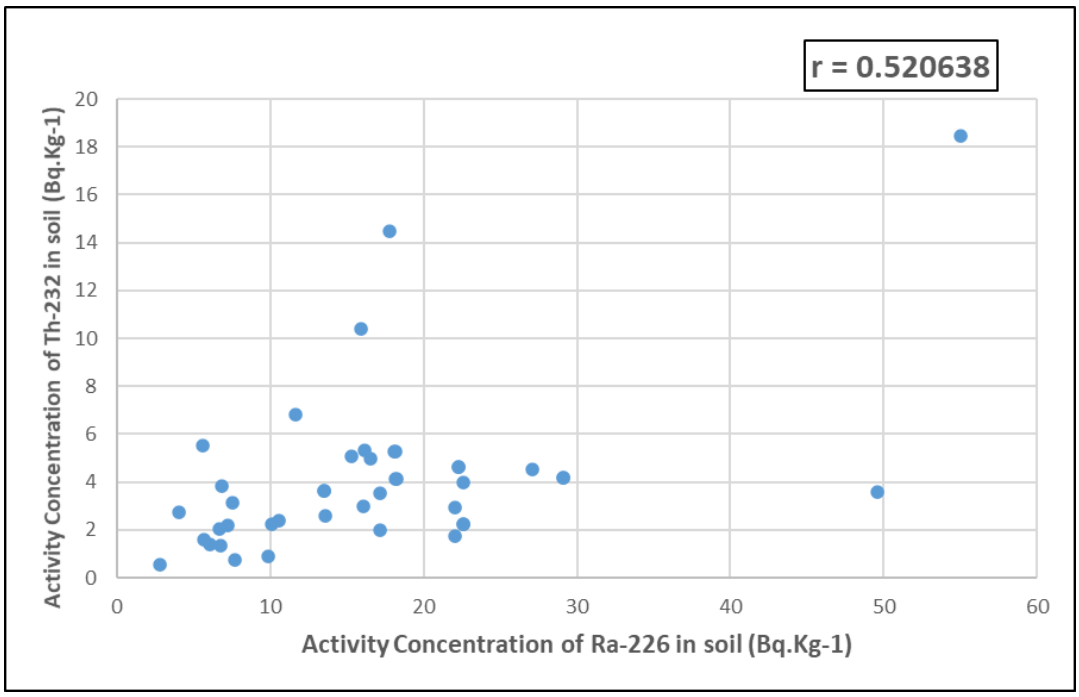

Figure 4-2 The correlation between ^{226}Ra and ^{232}Th in soil samples in Abu Dhabi Emirate

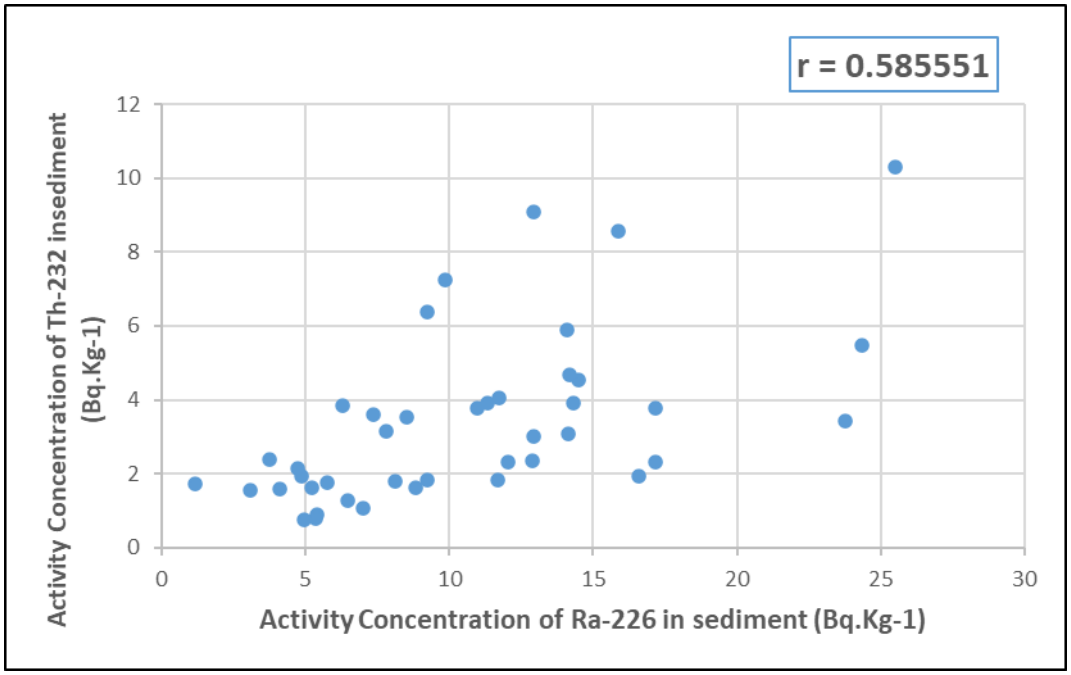

Figure 4-3 The correlation between ^{226}Ra and ^{232}Th in shore sediment samples in Abu Dhabi Emirate

The insignificant positive correlation coefficient (r) between ^{226}Ra and ^{232}Th in soil and shore sediment of Abu Dhabi Emirate show that the activity concentration values of ^{226}Ra and ^{232}Th ratio considerable gradually changed because of environmental conditions such as winds direction and continuous tide movement. These conditions also may be attributed to the movement of seawater currents along this area of the Gulf hence the variation in sedimentation rate of the soil between the shore and the part of bottom of the Gulf nearby the shore.

The correlation coefficient (r) of ^{40}K in soil, sediment and Gulf water are represented in Figures 4.4, 4.5 and 4.6 respectively. Figure 4.4 illustrates a positive correlation coefficient with value of (0.265) between activity concentration of ^{40}K in soil and shore sediment. This correlation values deduces that there is insignificant relation between ^{40}K in soil and shore sediment and its movement from one to another site by the effect of tide movement and seawater currents.

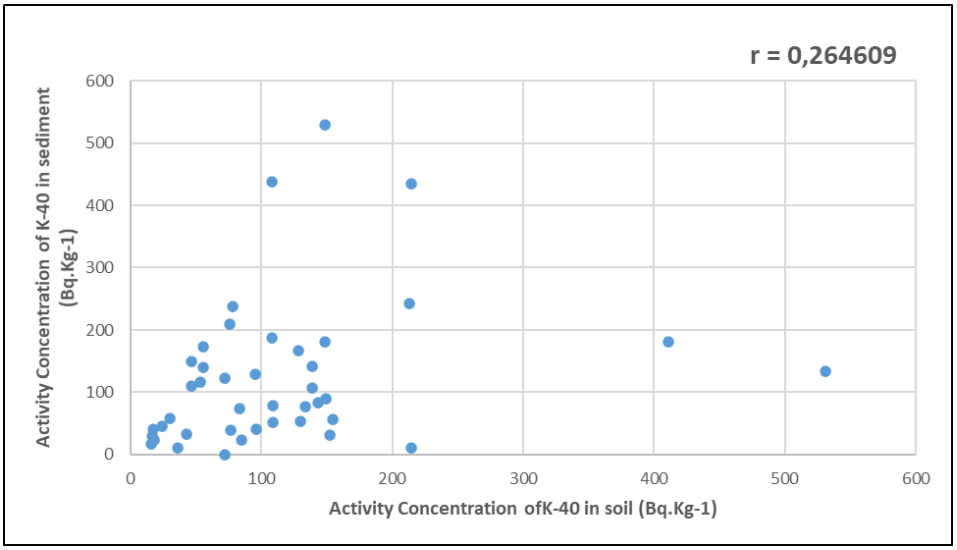

Figure 4-4 The correlation between ^{40}K in soil and shore sediment in Abu Dhabi Emirate

Figure 4-5 shows a negative correlation coefficient with value of (-0.011) between activity concentration of ^{40}K in soil and Gulf water. This indicates no relation and illustrate that ^{40}K had not been transferred from soil to gulf water under the effect of tide movement and continuous seawater currents in Abu Dhabi Emirate.

The correlation coefficient (r) between activity concentrations of ^{40}K in shore sediment and in Gulf water for Abu Dhabi Emirate illustrated in Figure 4-6 , it is insignificant positive correlation coefficient with value of (0.179) which show us that the transfer of ^{40}K from shore sediment to Gulf water is very low.

This conclusion may explain why the activity concentrations of ^{40}K in soil were higher than that in shore sediment and in the same time the transfer of ^{40}K to Gulf water was low that reflects the low concentrations activity of ^{40}K in Gulf water samples collected from Abu Dhabi Emirate.

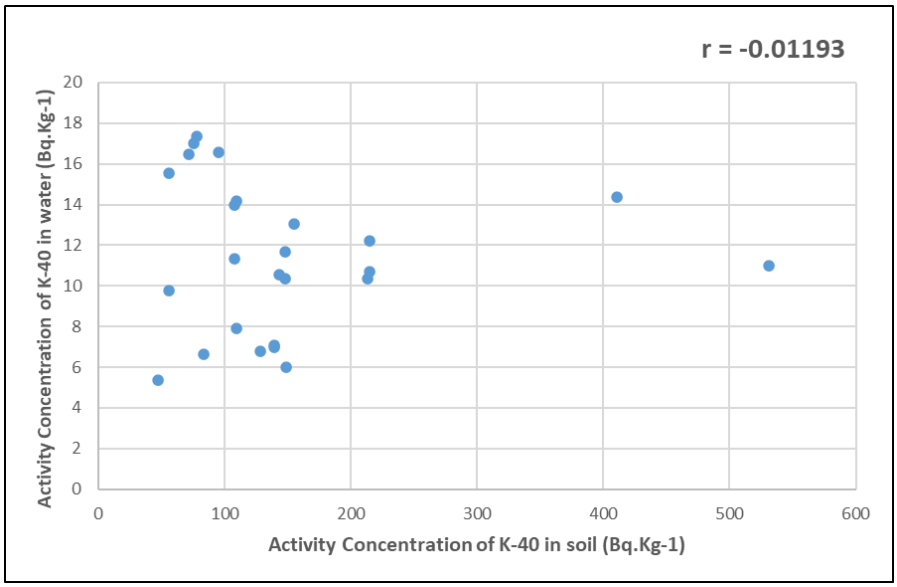

Figure 4-5 The correlation between ^{40}K in soil and Gulf water samples in Abu Dhabi Emirate

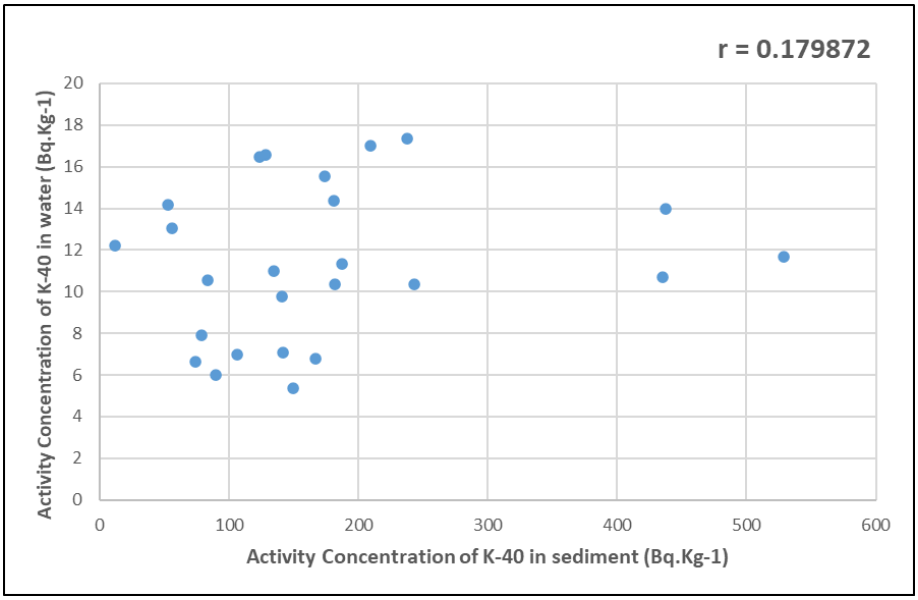

Figure 4-6 The correlation between ^{40}K in shore sediment and Gulf water in Abu Dhabi Emirate

It is noticeable that there are values for the results that may seem to be outliers' values, but they are few compared to the number of samples that were measured, in addition to the fact that these values did not exceed the global average concentrations of natural radioactive elements. Comparing this study results with the results of nearby countries shows, as we mentioned earlier, that the concentration levels obtained in this study are lower than the concentration levels in those countries. the slight variation in the radioactivity content in soil samples may also be explained by the variations in soil type, formation, and transport

processes due to changes in water currents in the Gulf and along water near the shore for a long period of time (Baeza *et al*, 1995; Belivermis *et al*, 2010).

These outlier values may influence Correlation Coefficient (r) by obtaining a negative relationship in some cases, but we cannot rule out these results. On the other hand, the Correlation Coefficient (r) relationship that we sought to obtain is an additional and directing factor that may explain to us the relationship between the concentrations of natural radioactive elements in soil and sediments and Water, but it is not the main objective of this study, so a detailed study of these areas with relatively high levels is required in the future.

4.4.5. Radiation Dose Assessments for Abu Dhabi Emirate Samples

The assessment of the potential exposure of an individual to radioactivity present in the soils and the shore sediments along Abu Dhabi coast has been carried out utilizing different indices. They are calculated as follow:

4.4.5.1. Radium Equivalent (Ra_{eq}) Calculation Results:

The radium equivalent concept allows a single hazard index to describe the gamma output from different mixtures of Radium (Uranium), Thorium and Potassium in the soil and sediment samples. Radium equivalent dose (Ra_{eq}) is used to estimate the hazards related to materials that include ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg. This index is mathematically defined as:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \qquad \textbf{Equation 4-1}$$

Where: C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, and this formula is based on the estimation that 1 Bq/kg of ^{226}Ra, 0.7 Bq/kg of ^{232}Th or 13.0 Bq/kg of ^{40}K produce the same gamma dose rate (Alaamer, 2012; Ramasamy *et al*., 2009; Sroor *et al*., 2002). The Ra_{eq} limit should be less than 370 Bq/kg (UNSCEAR, 2015).

The radium equivalent activities were determined for the soil and shore sediment samples along the Abu Dhabi coast and presented in Tables 4.7 and 4.8. The results indicate that the radium equivalent activities of soil are higher than that of the shore sediment in most of the collected samples from the shore in Abu Dhabi Emirate. The radium equivalent activities of soil samples were ranged from 10 to 96.3 with an mean of 33.83 Bq/kg, while for the shore sediment samples it ranged from 4.5 to 70.7, with an mean value of 23.91 Bq/kg. These values are much lower than the limit of 370 Bq/kg, as reported in UNSCEAR (2008), and

are also comparable with previous reported values in many neighbouring countries (Abd El Wahab & El Nahas, 2013; Al-Ghamdi *et al.*, 2016; El-Taher & Madkour, 2013).

Table 4-7 Radiation Hazard Indices from soil for Abu Dhabi Emirate

(Sample Code)	Raeq (Bq/kg)	D (nGy/h)	AED (mSv/y)	Hex	I_γ	Iα
S1	16.9	8.6	0.01	0.05	0.07	0.04
S2	19.4	9.5	0.01	0.05	0.07	0.05
S3	40.7	20.5	0.03	0.11	0.16	0.09
S4	60.5	27.1	0.03	0.16	0.21	0.25
S5	31.7	15.2	0.02	0.08	0.12	0.09
S6	96.3	44.9	0.06	0.26	0.35	0.28
S7	31.7	15.2	0.02	0.08	0.12	0.09
S8	40.6	20.4	0.03	0.11	0.16	0.09
S9	13.9	7.0	0.01	0.04	0.05	0.03
S10	22.0	11.4	0.01	0.06	0.09	0.04
S11	22.7	11.9	0.01	0.06	0.09	0.03
S12	23.4	11.6	0.01	0.06	0.09	0.03
S13	62.4	31.4	0.04	0.17	0.24	0.08
S14	39.6	19.3	0.02	0.11	0.14	0.11
S15	46.5	22.5	0.03	0.13	0.17	0.15
S16	22.5	11.6	0.01	0.06	0.12	0.11
S17	59.5	31.3	0.04	0.17	0.09	0.09
S18	38.6	18.6	0.02	0.11	0.11	0.11
S19	45.4	21.5	0.03	0.12	0.08	0.07
S20	17.0	15.2	0.02	0.09	0.31	0.09
S21	32.1	11.1	0.01	0.06	0.13	0.08
S22	23.9	14.2	0.02	0.08	0.14	0.11
S23	30.8	10.2	0.01	0.06	0.17	0.15
S24	21.9	40.0	0.05	0.21	0.12	0.11
S25	75.7	17.0	0.02	0.09	0.09	0.09
S26	34.5	18.6	0.02	0.10	0.11	0.11
S27	38.6	21.6	0.03	0.12	0.08	0.07
S28	45.4	16.0	0.02	0.09	0.16	0.14
S29	33.8	12.1	0.01	0.07	0.14	0.11
S30	26.1	14.2	0.02	0.08	0.04	0.02
S31	30.8	10.2	0.01	0.06	0.12	0.06
S32	21.9	21.1	0.03	0.12	0.09	0.08
S33	44.3	18.0	0.02	0.10	0.09	0.07
S34	37.6	4.8	0.01	0.03	0.11	0.08
S35	10.0	15.1	0.02	0.08	0.08	0.08
S36	30.5	12.1	0.01	0.07	0.06	0.05
S37	25.7	11.6	0.01	0.07	0.04	0.03
S38	24.0	14.1	0.02	0.08	0.03	0.03
S39	29.7	10.9	0.01	0.06	0.03	0.03
S40	24.2	7.10	0.01	0.04	0.06	0.05
S41	16.2	5.7	0.01	0.03	0.04	0.04
S42	12.1	4.3	0.01	0.02	0.02	0.01
World Limits	**≤370.0**	**76.0**	**<0.09**	**≤1**	**≤1**	**≤1**

Table 4-8 Radiation Hazard Indices from shore sediments for Abu Dhabi Emirate

(Sample Code)	R_{aeq} (Bq/kg)	D (nGy/h)	AED (mSv/y)	Hex	I_γ	I_α
SS1	20.9	10.7	0.01	0.06	0.08	0.05
SS2	32.0	16.9	0.02	0.09	0.13	0.06
SS3	4.5	2.1	0.00	0.01	0.02	0.01
SS4	33.9	15.6	0.02	0.09	0.12	0.12
SS5	14.9	7.1	0.01	0.04	0.06	0.04
SS6	39.5	20.4	0.02	0.11	0.16	0.07
SS7	13.2	6.7	0.01	0.04	0.05	0.02
SS8	70.7	36.4	0.04	0.20	0.28	0.13
SS9	33.1	17.1	0.02	0.09	0.13	0.05
SS10	13.0	6.7	0.01	0.04	0.05	0.02
SS11	12.3	6.5	0.01	0.03	0.05	0.02
SS12	25.2	13.1	0.02	0.07	0.10	0.04
SS13	25.0	13.2	0.02	0.07	0.10	0.04
SS14	24.7	12.1	0.01	0.07	0.09	0.06
SS15	48.8	28.0	0.03	0.14	0.22	0.03
SS16	50.9	27.8	0.03	0.15	0.21	0.05
SS17	44.4	21.5	0.03	0.12	0.17	0.12
SS18	25.0	12.5	0.02	0.07	0.10	0.05
SS19	27.4	13.9	0.02	0.08	0.11	0.06
SS20	29.3	14.5	0.02	0.08	0.11	0.07
SS21	16.5	7.9	0.01	0.05	0.06	0.04
SS22	30.9	15.3	0.02	0.09	0.12	0.07
SS23	40.8	20.3	0.02	0.11	0.16	0.08
SS24	30.6	15.7	0.02	0.09	0.12	0.06
SS25	32.4	15.9	0.02	0.09	0.12	0.09
SS26	6.7	2.9	0.00	0.02	0.02	0.03
SS27	24.0	11.8	0.01	0.07	0.09	0.06
SS28	10.5	5.0	0.01	0.03	0.04	0.03
SS29	19.6	9.5	0.01	0.05	0.07	0.06
SS30	30.1	14.1	0.02	0.08	0.11	0.06
SS31	23.1	10.7	0.01	0.06	0.08	0.08
SS32	23.2	10.5	0.01	0.06	0.08	0.09
SS33	21.4	9.9	0.01	0.06	0.08	0.07
SS34	8.2	3.8	0.00	0.02	0.03	0.03
SS35	11.7	5.7	0.01	0.03	0.04	0.03
SS36	9.9	4.7	0.01	0.03	0.04	0.03
SS37	11.5	5.1	0.01	0.03	0.04	0.04
SS38	10.6	5.2	0.01	0.03	0.04	0.02
SS39	8.4	4.1	0.00	0.02	0.03	0.02
SS40	29.0	14.2	0.02	0.08	0.11	0.07
SS41	10.0	4.7	0.01	0.03	0.04	0.03
SS42	6.5	3.1	0.00	0.02	0.02	0.02
World Limits	**≤370.0**	**76.0**	**0.09**	**≤1**	**≤1**	**≤1**

4.4.5.2. Outdoor Absorbed Dose Rate (D) Calculation

The absorbed dose rate from external gamma radiation at one meter above the ground was determined from the measured activities of ^{226}Ra, ^{232}Th and ^{40}K in the soil and shore

sediment samples using the next equation described as follow. The gamma radiation field is approximately calculated for a height of one meter above the ground surface in each location.

$$D = 0.462\ C_U + 0.604\ C_{Th} + 0.0417\ C_K \qquad \textbf{Equation 4-2}$$

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, 2000). The C_K, C_U, C_{Th} are the activity concentration of ^{40}K, $^{238}U(^{226}Ra)$ series and ^{232}Th series respectively, expressed in Bq/kg dry weight soil.

The results show that the absorbed dose rate values for soil are varied from 4.3 to 44.9 nGy/hr., with an mean value of, 16.3 nGy/hr. whereas these values for shore sediment samples are varied from 2.1 to 36.4 nGy/hr., with an mean value of, 11.97 nGy/hr. These results indicate that the Absorbed Dose Rate values for soil are higher than that of sediment.

Also, the Absorbed Dose Rate of both of soil and shore sediment are found to be lower than the world mean value of 76 nGy/hr as reported in the UNSCEAR (2008).

4.4.5.3. Annual Effective Dose (AED) Calculated Results

A conversion factor of 0.7 Sv/year and an outdoor occupancy factor of 0.2 Sv/year UNSCEAR (2000), were used to estimate Annual Effective Dose Rates to human. The Annual Effective Dose (AED) for Soil and shore sediment are determined and given in Tables 4.12 and 4.13. The results show that the AED values due to soil samples range from 0.01 to 0.06 mSv/year, with an mean of 0.02 mSv/year. While, for the shore sediment samples, the Annual Effective Dose (AED) varies from 0.0 to 0.04 mSv/year., with an mean value of, 0.0145 mSv/year. The results indicate that Annual Effective Dose due to soil is higher than that of the shore sediment and both are lower than the world mean Annual Effective Dose (0.09 mSv/year) from outdoor terrestrial gamma radiation (UNSCEAR, 2008).

4.4.5.4. External Hazard Index (Hex) Calculation Results

A widely used hazard index (reflecting the external exposure) called the External Hazard Index (H_{ex}). The External Hazard Index is a relation that quantifies the exposure factor and an evaluation of the hazard of the natural gamma radiation. The external hazard index (H_{ex}) is calculated from the following equation (Beretka & Mathew, 1985; Mujahid *et al.*, 2008);

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1$$ **Equation 4-3**

Where: A_{Ra}, A_{Th}, and A_K are the mean activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg. The safe value of this index must be less than 1 (UNSCEAR, 2008).

It is noticed that the mean values of the external hazard index for soils and shore sediments are 0.09 and 0.06 respectively.

The value of this index must be less than unity in order to keep the radiation hazard insignificant (UNSCEAR, 2008). Since the values of the study area are less than unity, therefore, according to Radiation Protection 112 report, this region is assumed to be safe for the population (European Commission, 1999). But also, there are some locations, as mentioned earlier, should be subjected for following up assessment of the activity concentration values of the natural radionuclides to assure safety for different activities.

4.4.5.5. Gamma Index (Iγ)

The European Commission has proposed an index called the gamma index (Iγ) defined by the following relation (European Commission, 1999). The gamma index (Iγ) has been introduced to account for the combined impact of ^{226}Ra, ^{232}Th and ^{40}K as radiological hazard associated with soil.

$$I\gamma = A_{Ra}/300 + A_{Th}/200 + A_K/3000 \leq 1$$ **Equation 4-4**

Where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, 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 (European Commission, 1999). Thus, Iγ can be used for identifying safe materials for construction purpose. According to the European Commission recommendations, the materials that do not increase the annual effective dose of a member of public by 0.3 mSv at the most should be exempted from all restrictions concerning radioactivity hazard. On the other hand, the doses higher than 1 mSv/y are allowed only for exceptional cases where materials are used locally, Table 4-6 & Table 4-7.

4.4.5.6. Alpha Index (Iα)

The alpha index, also known as the internal hazard index, is a useful tool in assessing internal hazard from alpha activity from building materials. The alpha index can be calculated as:

$$I_\alpha = A_{Ra}/200 \qquad \textbf{Equation 4-5}$$

Where A_{Ra} is the specific activity of ^{226}Ra. According to European commission recommendations (European Commission, 1999) the alpha index for safe building materials should be less than 1, corresponding to an ^{222}Rn concentration of 200 Bq/m3, as shown in Table 4-7 & Table 4-8.

4.5. Results and Discussion of Dubai and the Northern Emirates Samples

The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, ± 1σ uncertainties, in the coastal area samples (soil, shore sediment and Gulf water) of Dubai and the Northern Emirates region are presented in the following sections.

4.5.1. Results of Soil Sample Activity

The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, ± 1σ uncertainties of the Soil samples in the coastal area of Dubai and the Northern Emirates region are presented in Table 4.9.

4.5.1.1. Radium-226 and Thorium-232 Activity Results

The results indicate that the maximum concentrations for ^{226}Ra and ^{232}Th are 23.09 and 9.70 whereas the minimum concentrations are 1.80 and 0.68 Bq/kg respectively. The mean concentrations values of both ^{226}Ra and ^{232}Th are 9.1 and 2.72 Bq/kg respectively. These results show that the mean activity concentration values of the naturally occurring radionuclides in the collected soil samples from Dubai and the Northern Emirates region are lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000).

Table 4-9 Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples ± 1σ uncertainties for Dubai and the Northern Emirates

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S43	20.77	±	1.03	5.94	±	0.29	135.6	±	6.78	0.10	±	0.01
S44	1.80	±	0.09	1.65	±	0.08	30.02	±	1.50	0.11	±	0.05
S45	5.53	±	0.27	1.35	±	0.06	21.96	±	1.10	0.57	±	0.02
S46	8.67	±	0.43	2.66	±	0.13	35.98	±	1.80	0.19	±	0.01
S47	6.08	±	0.30	1.37	±	0.06	16.11	±	0.80	0.24	±	0.01
S48	5.65	±	0.28	1.61	±	0.08	16.47	±	0.82	0.15	±	0.01
S49	9.87	±	0.49	1.50	±	0.07	53.23	±	2.66	0.80	±	0.04
S50	5.16	±	0.25	0.78	±	0.03	5.04	±	0.25	0.18	±	0.01
S51	3.54	±	0.17	0.96	±	0.04	21.66	±	1.08	0.08	±	0.01
S52	6.52	±	0.32	0.68	±	0.03	17.57	±	0.87	0.21	±	0.01
S53	10.68	±	0.53	1.60	±	0.08	23.72	±	1.18	0.18	±	0.01
S54	9.26	±	0.46	4.38	±	0.21	139.94	±	7.00	0.16	±	0.01
S55	5.07	±	0.25	1.33	±	0.06	122.47	±	6.12	0.14	±	0.07
S56	8.87	±	0.44	1.52	±	0.07	35.00	±	1.75	0.15	±	0.01
S57	5.90	±	0.29	1.70	±	0.08	22.83	±	1.14	0.23	±	0.01
S58	6.60	±	0.33	2.18	±	0.10	36.57	±	1.82	0.20	±	0.01
S59	10.91	±	0.54	0.82	±	0.04	43.76	±	2.18	0.20	±	0.01
S60	17.37	±	0.86	8.55	±	0.42	32.76	±	1.63	0.18	±	0.01
S61	8.84	±	0.44	2.66	±	0.13	50.61	±	2.53	0.15	±	0.01
S62	23.09	±	1.15	9.70	±	0.48	109.69	±	5.48	0.30	±	0.01
S63	9.25	±	0.46	4.35	±	0.21	139.94	±	7.00	0.16	±	0.01
S64	10.92	±	0.54	2.33	±	0.11	64.50	±	3.22	0.46	±	0.01
S65	9.10	±	0.45	3.00	±	0.15	79.89	±	4.00	0.24	±	0.02
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**
Mean	**16.68**			**4.09**			**113.74**			**0.78**		

4.5.1.2. Potasium-40 Activity Results

The results indicated that the maximum concentration of ^{40}K is 139.94 Bq/kg and the minimum concentration was 5.04 Bq/kg with an mean value of 54.57 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected soil samples from Dubai and the Northern Emirates region are much lower than the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000). This result denotes that Dubai and the Northern emirates region have lower activity concentrations of ^{40}K than Abu Dhabi region as mentioned before in the previous section.

4.5.1.3. Cesium-137 Activity Results

The activity concentration values of ^{137}Cs in the measured soil samples of Dubai and the Northern Emirates region represented in Table 4-9. It is clearly appearing that the activity concentrations of ^{137}Cs range from 0.8 to 0.08 Bq/kg, with a mean value of 0.233 Bq/kg in the soil samples. These values of ^{137}Cs activity concentrations are lower than values measured for Abu Dhabi region. It is lower than or comparable for values reported in soils from Pakistan; 1.6 Bq/kg (Rafique, 2014), from Palestine; 2.8 Bq/kg (Abu Samreh *et al*., 2014), and from Suez Gulf, Egypt 0.1 Bq/kg (Salama *et al*., 2015).

4.5.1.4. Maximum Activity Concentrations

The maximum activity concentrations of ^{226}Ra and ^{232}Th as shown in Table 4-10 which were noticed for sites S43, S60 and S62 respectively (20.77 and 23.09 Bq/kg for ^{226}Ra and 8.55 and 9.7 Bq/kg for ^{232}Th) are also lower than the world mean activity for ^{226}Ra and ^{232}Th (UNSCEAR, 2000).

Table 4-10 The maximum activity concentrations observed for ^{226}Ra and ^{232}Th, ^{40}K and ^{137}Cs in soil samples ± 1σ uncertainties

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S43	20.77	±	1.03	---		---	135.6	±	6.78	---		---
S45	---		---	---		---	---		---	0.57	±	0.02
S49	---		---	---		---	---		---	0.80	±	0.04
S54	---		---	---		---	139.94	±	7.00	---		---
S60	---		---	8.55	±	0.42	---		---	---		---
S62	23.09	±	1.15	9.70	±	0.48	---		---	---		---
S63	---		---				139.94	±	7.00	---		---

4.5.2. Results of Shore Sediment Samples of Dubai and Northern Emirate Regions

The activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th, ^{40}K, and the man-made ^{137}Cs ± 1σ uncertainties, in the shore sediments samples of the coastal area of Dubai and the Northern Emirates region are presented in Table 4-11. The activity concentration values of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs are given in Bq/kg on a dry weight basis.

Table 4-11 Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in Shore Sediment samples ± 1σ uncertainties for Dubai and the Northern Emirates region

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
SS43	6.42	±	0.32	1.00	±	0.05	32.57	±	1.62	0.05	±	0.002
SS44	6.93	±	0.34	1.76	±	0.08	77.59	±	3.87	0.18	±	0.01
SS45	0.63	±	0.03	1.43	±	0.07	14.37	±	0.71	0.12	±	0.006
SS46	3.75	±	0.18	1.28	±	0.06	13.90	±	0.69	0.46	±	0.02
SS47	4.81	±	0.24	1.35	±	0.06	20.23	±	1.01	0.03	±	0.001
SS48	6.79	±	0.33	1.69	±	0.08	24.98	±	1.24	0.06	±	0.003
SS49	5.22	±	0.26	1.32	±	0.06	35.94	±	1.79	0.23	±	0.01
SS50	2.94	±	0.14	1.70	±	0.08	24.62	±	1.23	0.31	±	0.01
SS51	10.14	±	0.50	5.23	±	0.26	105.71	±	5.28	0.32	±	0.02
SS52	6.22	±	0.31	1.33	±	0.06	25.68	±	1.28	0.03	±	0.001
SS53	5.29	±	0.26	1.64	±	0.08	31.72	±	1.58	0.37	±	0.01
SS54	12.52	±	0.62	1.70	±	0.08	34.50	±	1.72	0.44	±	0.02
SS55	14.41	±	0.72	5.00	±	0.25	136.32	±	6.81	0.28	±	0.01
SS56	9.95	±	0.49	2.27	±	0.13	130.18	±	6.50	0.21	±	0.01
SS57	11.66	±	0.58	5.49	±	0.27	215.32	±	10.76	0.63	±	0.03
SS58	7.89	±	0.39	2.36	±	0.11	121.43	±	6.07	0.03	±	0.001
SS59	2.10	±	0.10	2.04	±	0.10	37.81	±	1.89	0.07	±	0.003
SS60	6.82	±	0.34	1.82	±	0.09	65.69	±	3.28	0.88	±	0.04
SS61	8.88	±	0.44	2.45	±	0.12	147.60	±	7.38	0.29	±	0.01
SS62	4.82	±	0.24	2.29	±	0.11	24.60	±	1.23	0.31	±	0.01
SS63	2.14	±	0.10	7.81	±	0.39	9.04	±	0.45	0.03	±	0.001
SS64	2.62	±	0.13	1.62	±	0.08	50.56	±	2.52	0.15	±	0.007
SS65	1.65	±	0.08	0.78	±	0.03	33.77	±	1.68	0.41	±	0.02
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**
Mean	**6.29**			**2.41**			**61.48**			**0.26**		

4.5.2.1. Radium-226 and Thorium-232 Activity Results

The Results shows that the maximum activity concentrations for ^{226}Ra and ^{232}Th are 14.41 and 0.63 Bq/kg whereas the minimum concentrations are 7.81 and 0.78 Bq/kg respectively. The mean concentrations values of both ^{226}Ra and ^{232}Th are 6.28 and 2.40 Bq/kg respectively. These results show that the mean activity concentration values of the naturally occurring radionuclides; ^{226}Ra and ^{232}Th, in the collected shore sediment samples from the coastal area of Dubai and the Northern Emirates region are much lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000). As shown in Table

4.16 the maximum activity concentration values of ^{226}Ra and ^{232}Th are presented for sites SS55, SS57 and SS63 with activity values of 14.41, 11.66 for ^{226}Ra and 5.49, 7.8 Bq/kg respectively. All these values are lower than the world mean by lower than the half 35 and 30 Bq/kg, (UNSCEAR, 2000) and black sand samples (Abdel-Rahman *et al.*, 2017).

4.5.2.2. Potasium-40 Activity Results

The activity concentrations of ^{40}K in the shore sediment samples collected from Dubai and the Northern Emirates region are represented in Table 4-12. The results indicate that the maximum concentration of ^{40}K is 215.32 Bq/kg and the minimum concentration was 9.04 Bq/kg with an mean value of 61.48 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected shore sediment samples is much lower than the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000).

4.5.2.3. Cesium-137 Activity Analysis

The results indicate that the presence of ^{137}Cs in the shore sediment was evident for fallout, its maximum activity measured in Dubai region is 0.88 Bq/kg and the minimum is 0.03 Bq/kg, with an mean value of 0.25 Bq/kg, as presented in Table 4-12 and Figure 4.24. These activity values were found to be less than the values from the pre-Chernobyl period cited in the literature for marine sediments from different regions of the world (IAEA, 2006).

4.5.2.4. Maximum Activity Concentrations

All the maximum activity concentration values presented in Table 4-12 for the terrestrial radionuclides ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs, in the shore sediments samples of the coastal area of Dubai and the Northern Emirates region, are found to be 14.41, 7.81 and 215.32 Bq/kg respectively. These values are lower than the world mean which are 35, 30 and 400 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively (UNSCEAR, 2000).

Table 4-12 The maximum activity concentrations observed for ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in shore sediment samples ± 1σ uncertainties

Sample Code	**^{226}Ra (Bq/kg)**			**^{232}Th (Bq/kg)**			**^{40}K (Bq/kg)**			**^{137}Cs (Bq/kg)**		
SS55	**14.41**	±	0.72	5.00	±	0.25	136.32	±	6.81	0.28	±	0.01
SS57	**11.66**	±	0.58	**5.49**	±	0.27	**215.32**	±	10.76	**0.63**	±	0.03
SS60	6.82	±	0.34	1.82	±	0.09	65.69	±	3.28	**0.88**	±	0.04
SS63	2.14	±	0.10	**7.81**	±	0.39	9.04	±	0.45	0.03	±	0.001
Mean	**6.28**			**2.4**			**61.48**			**0.25**		

4.5.3. Results of ^{40}K in Gulf Water Samples of Dubai and the Northern Emirate Regions

The activity concentrations of ^{40}K in the Gulf water samples collected from Dubai and the Northern Emirates region are represented in Table 4-13. The results indicate that the maximum activity concentration of ^{40}K is 14.39 Bq/kg and the minimum concentration is 3.19 Bq/kg with an mean value of 9.2 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected Gulf water samples from these areas are too much lower than the observed world mean of ^{40}K (UNSCEAR, 2000).

This indicates that the transfer of ^{40}K from soil or shore sediment to Gulf water in Dubai and the Northern Emirates region is negligible. Both the primordial ^{238}U and ^{232}Th and the anthropogenic ^{137}Cs were found to be lower than the HpGe ϒ-spectrometer limit of detection

Table 4-13 Activity concentrations of ^{40}K in Gulf water samples ± 1σ uncertainties for Dubai and the Northern Emirates

Code	Activity Bq L^{-1}	Code	Activity Bq L^{-1}
W26	12.54 ± 0.62	W36	9.79 ± 0.48
W27	12.34 ± 0.61	W37	5.97 ± 0.29
W28	6.56 ± 0.32	W38	9.52 ± 0.47
W29	8.30 ± 0.41	W39	8.79 ± 0.43
W30	11.81 ± 0.59	W40	11.29 ± 0.56
W31	3.26 ± 0.16	W41	3.19 ± 0.15
W32	9.72 ± 0.48	W42	12.94 ± 0.64
W33	11.53 ± 0.57	W43	6.74 ± 0.34
W34	4.29 ± 0.21	W45	10.67 ± 0.53
W35	14.93 ± 0.72	W46	9.92 ± 0.49
Minimum	**3.19 ± 0.15**		
Maximum	**14. 93 ± 0.72**		
Mean	**9.205**		

4.5.4. Correlation Coefficient (r) between ^{226}Ra and ^{232}Th and ^{40}K Activities for Dubai and the Northern Emirates

The correlation between ^{226}Ra and ^{232}Th activity concentrations for soil and shore sediment samples collected from Dubai and the Northern Emirates was calculated. Also, the correlation for ^{40}K activity concentrations in soil, shore sediment and Gulf water were performed to show if there are any relationship between these natural radionuclides in transformation and movement due to sea currents in the Gulf and tide waves along the shore.

The natural concentrations of ^{226}Ra and ^{232}Th in the Earth's crust are 2.9 and 9.6 ppm, respectively; which corresponds to a specific activity of 36.0 and 39 Bq/kg respectively (UNSCEAR, 2000).

The correlation between ^{226}Ra and ^{232}Th activity concentrations in the collected soil and shore-sediment samples is depicted in Figures 4-7 and 4-8 respectively. The calculated Correlation Coefficient (r) for ^{226}Ra and ^{232}Th is found to be positive with value of (0.8489) for soil samples. The positive and significant Correlation Coefficient value is quite logical, as both have the same terrestrial origin.

On the other hand, the calculated Correlation Coefficient (r) between ^{226}Ra and ^{232}Th activity concentrations in the shore-sediment samples was found to be positive with value of (0.3274) which indicate unsignificant correlation between ^{226}Ra and ^{232}Th in shore sediment samples. The radioactivity content in shore-sediment depends on the rock type from which the sediment is formed, the atmospheric deposition (dry and wet), seawater flux or currents and the physical and chemical properties of the sediment and sedimentation process. All the previous environmental changes and or factors affect the changes in ^{226}Ra and ^{232}Th activity ratios.

The Correlation Coefficient (r) of radioactive Potassium (^{40}K) between soil, sediment and Gulf water samples for Dubai and the Northern Emirates region are represented in Figures 4-9, 4-10 and 4-11 respectively. Figure 4-9 illustrates a negative Correlation Coefficient (r) with value of (-0.126) between activity concentration of ^{40}K in soil and in shore sediment. This Correlation Coefficient (r) value deduces that there is a unsignificant relation between ^{40}K in soil and sediment and its movement from one to another by the effect of tide movement and seawater currents.

In Figure 4.10, the Correlation Coefficient (r) shows a negative value of (-0.0996) between activity concentrations of ^{40}K in soil and its activity in Gulf water. This relation may illustrate that ^{40}K had a very low transferred from soil to Gulf water under the effect of tide movement and continuous seawater currents in that region.

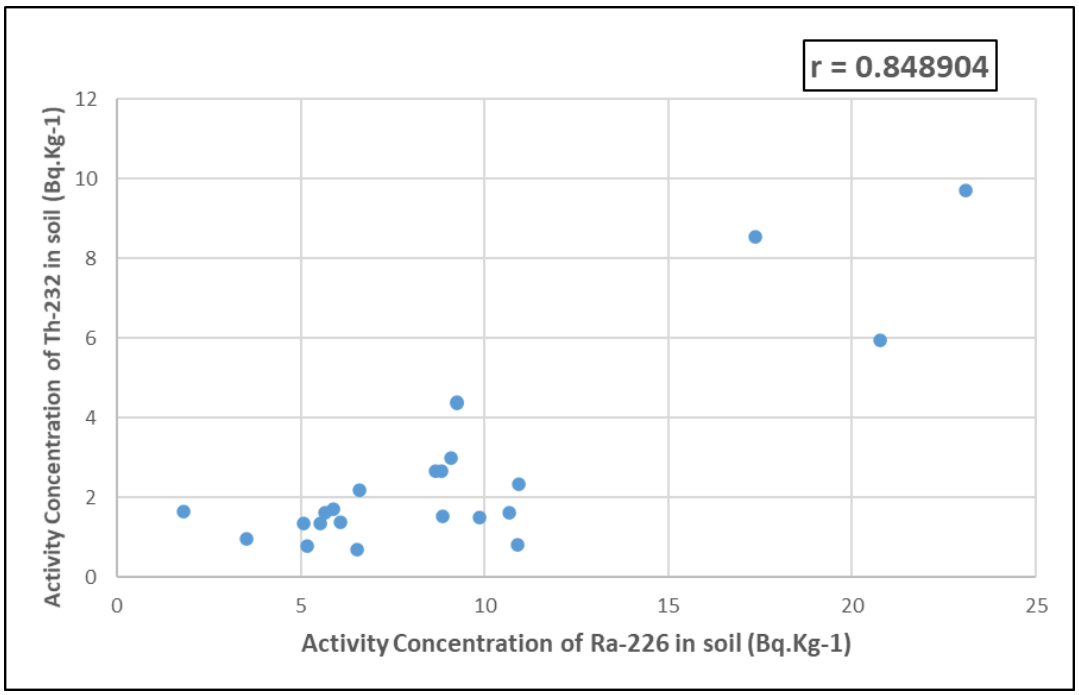

Figure 4-7 The correlation between ^{226}Ra and ^{232}Th in soil samples collected from Dubai and the Northern Emirates

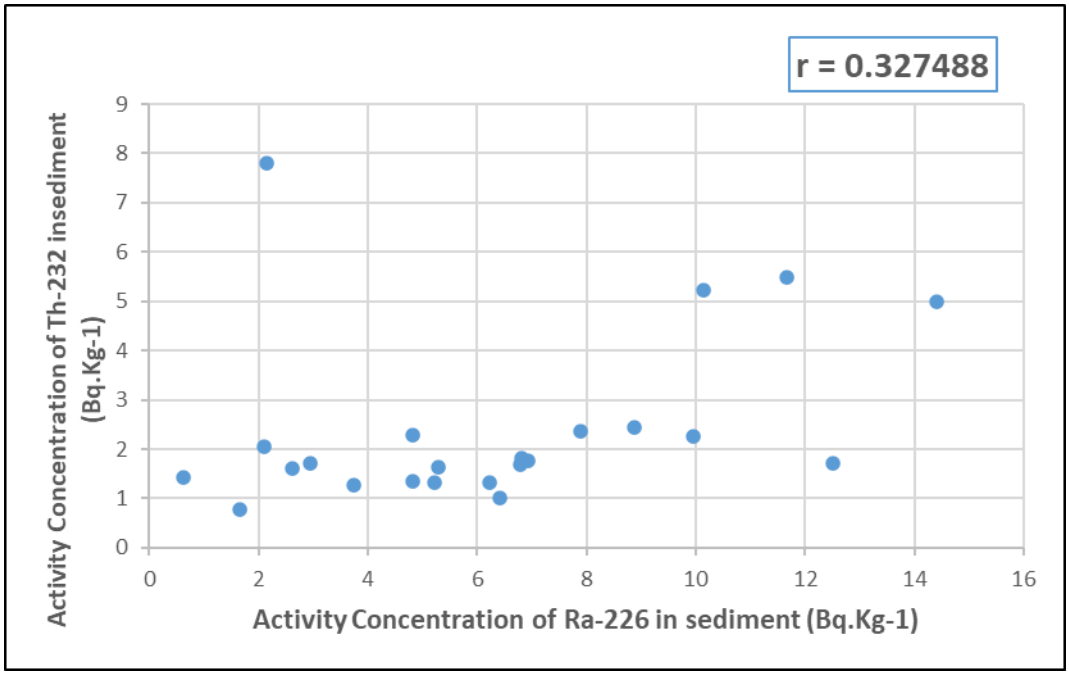

Figure 4-8 The correlation between ^{226}Ra and ^{232}Th in shore sediment samples collected from Dubai and the Northern Emirates

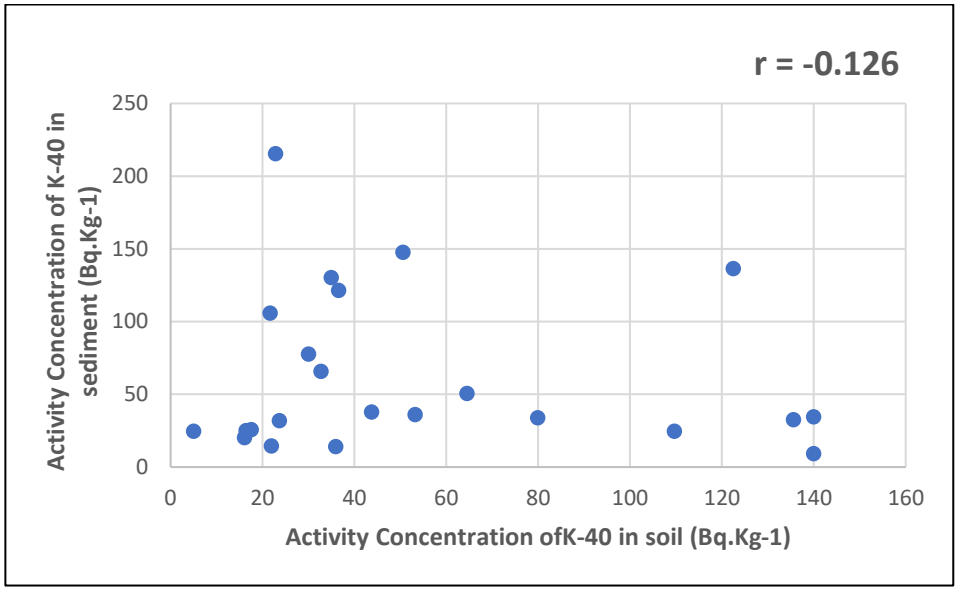

Figure 4-9 The correlation between ^{40}K in soil and in shore sediment samples collected from Dubai and the Northern Emirates

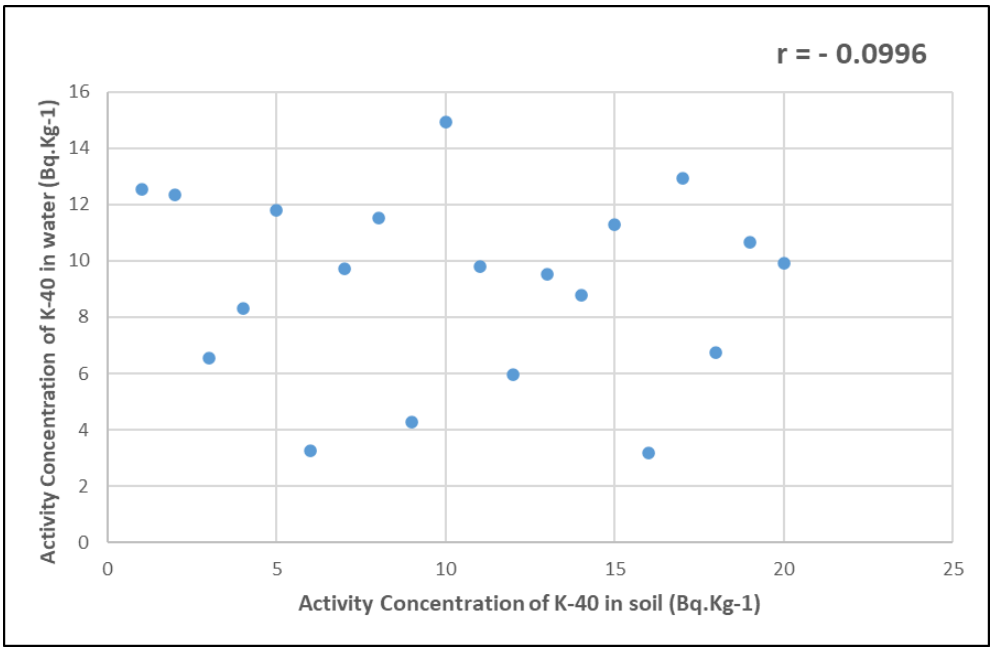

Figure 4-10 The correlation between 40K in soil and Gulf water samples collected from Dubai and the Northern Emirates

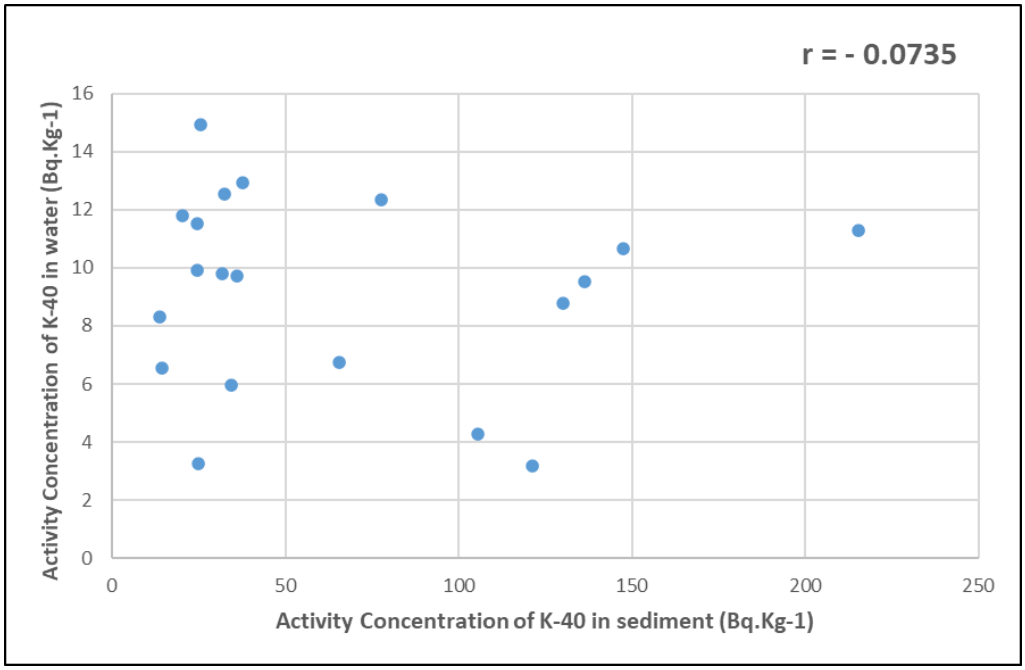

Figure 4-11 The correlation between ^{40}K in shore sediment and Gulf water samples collected from Dubai and the Northern Emirates

The Correlation Coefficient (r) between activity concentrations of ^{40}K in sediment and that in Gulf water for Dubai and the Northern Emirates region is illustrated in Figure 4-11, the results show a negative correlation with value of (-0.0735). This correlation deduces that the transfer of ^{40}K from shore sediment to Gulf water was happened at very low level. This conclusion may explain why the activity concentrations of ^{40}K in soil were higher than that in shore sediment and at the same time the transfer of ^{40}K to Gulf water was low and that reflects the very low activity concentrations of ^{40}K in sea Gulf samples collected from Dubai and the Northern Emirates region.

It is noticeable that there are values for the results that may seem to be outliers' values, but they are few compared to the number of samples that were measured, in addition to the fact that these values did not exceed the global average concentrations of natural radioactive elements. Comparing this study results with the results of nearby countries shows, as we mentioned earlier, that the concentration levels obtained in this study are lower than the concentration levels in those countries. the slight variation in the radioactivity content in soil samples may also be explained by the variations in soil type, formation, and transport processes due to changes in water currents in the Gulf and along water near the shore for a long period of time (Baeza *et al*, 1995; Belivermis *et al*, 2010).

These outlier values may influence Correlation Coefficient (r) by obtaining a negative relationship in some cases, but we cannot rule out these results. On the other hand, the

Correlation Coefficient (r) relationship that we sought to obtain is an additional and directing factor that may explain to us the relationship between the concentrations of natural radioactive elements in soil and sediments and Water, but it is not the main objective of this study, so a detailed study of these areas with relatively high levels is required in the future.

4.5.5. Radiation Dose Assessments Results

The assessment of the potential exposure of an individual to radioactivity present in the soils and the shore sediments along Dubai and the Northern Emirates coast has been carried out utilizing different indices. They are calculated based on the same equations given before.

4.5.5.1. Radium Equivalent (Ra_{eq}) Results

The radium equivalent activities were determined for the soil and shore sediment samples along Dubai and the Northern Emirates coast and presented in Tables 4-14 and 4-15. The results indicate that the radium equivalent activities of soil are higher than that of the shore sediment in most of the collected samples from the shore in this region. The radium equivalent activities of soil samples are ranged from 4.7 to 38.7 with a mean of 13.5 Bq/kg. While for the shore sediment samples it is ranged from 3.7 to 34.6, with a mean value of 14.03 Bq/kg. These values are much lower than the world limit of 370 Bq/kg, as reported in the (UNSCEAR, 2000), and are also comparable with previous reported values in many neighbouring countries (Al-Ghamdi *et al*., 2016; Abd El Wahab & El Nahas, 2013; El-Taher & Madkour, 2013).

Table 4-14 Radiation hazard indexes from Soil for Dubai and Northern Emirates

Sample Code	R_{aeq} (Bq/kg)	D (nGy/h)	AED (mSv/y)	Hex	I_γ	I_α
S43	9.3	4.2	0.01	0.02	0.14	0.10
S44	9.1	7.1	0.01	0.04	0.02	0.01
S45	10.1	4.6	0.01	0.02	0.03	0.03
S46	4.7	2.3	0.00	0.01	0.05	0.04
S47	38.7	18.6	0.02	0.10	0.03	0.03
S48	6.3	3.2	0.00	0.02	0.03	0.03
S49	9.0	4.2	0.01	0.02	0.06	0.05
S50	15.0	7.0	0.01	0.04	0.02	0.03
S51	9.2	4.2	0.01	0.02	0.02	0.02
S52	9.1	4.2	0.01	0.02	0.03	0.03
S53	15.7	7.5	0.01	0.04	0.05	0.05
S54	6.6	2.9	0.00	0.02	0.10	0.05
S55	6.4	3.1	0.00	0.02	0.06	0.03
S56	8.7	4.0	0.00	0.02	0.05	0.04
S57	14.6	6.6	0.01	0.04	0.04	0.03

S58	25.3	12.9	0.02	0.07	0.05	0.03
S59	15.5	8.3	0.01	0.04	0.06	0.05
S60	13.5	6.3	0.01	0.04	0.11	0.09
S61	10.0	4.6	0.01	0.03	0.06	0.04
S62	12.3	5.8	0.01	0.03	0.16	0.12
S63	15.1	7.1	0.01	0.04	0.10	0.05
S64	32.0	14.5	0.02	0.09	0.07	0.05
S65	16.2	7.7	0.01	0.04	0.07	0.05
World Limits	**≤370.0**	**76.0**	**<0.09**	**≤1**	**≤1**	**≤1**

Table 4-15 Radiation Hazard Indices from shore sediments for Dubai and the Northern Emirates

Sample Code	**R_{aeq} (Bq/kg)**	**D (nGy/h)**	**AED (mSv/y)**	**Hex**	**I_γ**	**I_α**
SS43	10.1	4.8	0.01	0.03	0.04	0.03
SS44	14.9	7.5	0.01	0.04	0.06	0.03
SS45	3.7	1.8	0.00	0.01	0.01	0.00
SS46	6.6	3.0	0.00	0.02	0.02	0.02
SS47	8.2	3.8	0.00	0.02	0.03	0.02
SS48	11.0	5.1	0.01	0.03	0.04	0.03
SS49	9.6	4.6	0.01	0.03	0.04	0.03
SS50	7.1	3.4	0.00	0.02	0.03	0.01
SS51	25.0	12.3	0.02	0.07	0.10	0.05
SS52	9.9	4.6	0.01	0.03	0.04	0.03
SS53	9.9	4.7	0.01	0.03	0.04	0.03
SS54	17.4	8.0	0.01	0.05	0.06	0.06
SS55	31.1	15.3	0.02	0.09	0.12	0.07
SS56	22.3	11.3	0.01	0.06	0.09	0.05
SS57	34.6	17.9	0.02	0.10	0.14	0.06
SS58	19.8	10.2	0.01	0.06	0.08	0.04
SS59	7.7	3.9	0.00	0.02	0.03	0.01
SS60	14.0	6.9	0.01	0.04	0.05	0.03
SS61	22.7	11.8	0.01	0.06	0.09	0.04
SS62	9.8	4.6	0.01	0.03	0.04	0.02
SS63	13.9	6.5	0.01	0.04	0.05	0.01
SS64	8.5	4.4	0.01	0.02	0.03	0.01
SS65	5.1	2.7	0.00	0.01	0.02	0.01
World Limits	**≤370.0**	**76.0**	**<0.09**	**≤1**	**≤1**	**≤1**

4.5.5.2. Outdoor Absorbed Dose Rate (D) Results

The results show that the absorbed dose rate values for soil are varied from 2.3 to 18.6nGy/hr., with a mean value of 6.56 nGy/hr. Whereas these values for shore sediment samples are varied from 3.7 to 17.9 nGy/hr., with an mean value of, 14.03 nGy/hr. These results indicate that the absorbed dose rate values for shore sediment are higher than that of

soil. Also, the absorbed dose rate of both of soil and shore sediment is found to be lower than the world mean value of 76.0 nGy/hr reported in the UNSCEAR (2008) and other recent work (Shabaka *et al.,* 2020).

4.5.5.3. Annual Effective Dose (AED) Calculation Results

In order to estimate the Annual Effective Dose rates to human body, 0.7 and 0.2 Sv/year were used for conversion factor and the outdoor occupancy factor respectively as published by the UNSCEAR 2000. The Annual Effective Dose (AED) for soil and shore sediment of Dubai and the Northern emirates regions are given in Tables 4-14 and 4-15. The results show that the AED values for soil samples ranged from 0.0 to 0.02 mSv/year, with an mean of 0.009 mSv/year. While, for the shore sediment samples, the Annual Effective Dose (AED) varied from 0.0 to 0.02 mSv/year, with an mean value of 0.0086 mSv/year. The results indicate that annual effective dose of soil is approximately the same as that of the shore sediment and both of them are lower than the world mean annual effective dose (0.09 mSv/year) from outdoor terrestrial gamma radiation (UNSCEAR, 2000).

4.5.5.4. External Hazard Index (H_{ex}) Results

It is noticed that the mean values of the external hazard index for soils and sediments are 0.036 and 0.039 respectively.

The value of this index must be less than unity in order to keep the radiation hazard insignificant. Since the values of the study area are less than unity, therefore, this region is assumed to be safe for population according to European Commission (1999). But also, there are some locations, as mentioned earlier, which should be subjected for following up assessment of the activity concentration values of the natural radionuclides to assure safety for different activities.

The calculated hazard indices for Dubai and the Northern Emirates due to soil and shore sediments samples are given and tabulated in the following tables:

4.6. Results and Discussion of Islands Samples

The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs, ± 1σ uncertainties, in the coastal area samples (soil, shore sediment and Gulf water) of Islands are presented in the following sections.

4.6.1. Results of Islands Soil Sample Analysis

The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs, ± 1σ uncertainties, in the Soil samples of the coastal area of Islands are presented in Table 4-16.

Table 4-16 Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in soil samples ± 1σ uncertainties for Islands

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S66	2.30	±	0.11	1.86	±	0.09	22.95	±	1.14	0.05	±	0.01
S67	1.28	±	0.06	1.04	±	0.05	4.85	±	0.24	0.16	±	0.01
S68	2.97	±	0.14	1.41	±	0.07	19.14	±	0.96	0.11	±	0.01
S69	1.24	±	0.06	1.04	±	0.05	19.42	±	0.97	0.08	±	0.01
S70	35.86	±	1.79	7.99	±	0.39	316.20	±	15.8	0.46	±	0.02
S71	44.43	±	2.22	3.55	±	0.17	224.74	±	11.2	0.63	±	0.03
S72	3.25	±	0.16	2.46	±	0.12	36.02	±	1.80	7.00	±	0.35
S73	29.02	±	1.45	6.53	±	0.32	260.72	±	13.0	0.28	±	0.01
S74	3.99	±	0.19	1.49	±	0.07	46.29	±	2.31	0.60	±	0.03
S75	23.72	±	1.18	1.80	±	0.09	49.50	±	2.47	0.33	±	0.05
S76	36.96	±	1.84	5.39	±	0.26	137.06	±	6.85	6.26	±	0.31
S77	6.73	±	0.33	0.61	±	0.03	22.45	±	1.12	0.26	±	0.01
S78	34.67	±	1.73	16.44	±	0.82	488.69	±	24.4	0.11	±	0.01
S79	9.19	±	0.45	3.42	±	0.17	75.19	±	3.7	0.53	±	0.02
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**
Mean	**16.83**			**3.93**			**123.08**			**1.20**		

4.6.1.1. Radium-226 and Thorium-232 Activity Results of Island

The results indicate that the maximum activity concentrations for ^{226}Ra and ^{232}Th are 44.43 Bq/kg and 7.99 Bq/kg whereas the minimum activity concentrations are 1.280 Bq/kg and 0.61 Bq/kg respectively. The mean activity concentrations values of both ^{226}Ra and ^{232}Th are 16.82 Bq/kg and 3.68 Bq/kg respectively.

These results show that the mean activity concentration values of the naturally occurring radionuclides in the collected soil samples from Islands are lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000). The maximum activity

concentrations of ^{226}Ra and ^{232}Th as shown in Table 4-16 are noticed to be for sites S71, S76 for ^{226}Ra and for sites S70, S78 for ^{232}Th respectively (44.43, 36.93 Bq/kg for ^{226}Ra and 7.99, 16.44 Bq/kg for ^{232}Th). Hence the observed activity concentrations of ^{232}Th are found to be lower than the world mean activity for ^{232}Th which is 30 Bq/kg (UNSCEAR, 2000). Whereas the activity concentration values for ^{226}Ra are found to be higher than that the world mean; 35 Bq/kg (UNSCEAR, 2000) in both sites S71 and S76, hence the continuous assessment should be followed in the future for these sites.

4.6.1.2. Potasium-40 Activity in Islands

The results indicate that the maximum activity concentration of ^{40}K is 488.69 Bq/kg and the minimum activity concentration is 4.85 Bq/kg with an mean value of 123.08 Bq/kg. These results show that the mean activity concentration values of naturally occurring ^{40}K in the collected soil samples from Islands are much lower than the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000).

This result denotes that Islands territories have lower activity concentrations of ^{40}K than Abu Dhabi region as mentioned before. But also, as shown in Table 4-16, the site S78 has ^{40}K activity concentration (488.69 Bq/kg) higher than that of the world mean. Hence, this site (S78) is recommended for continuous assessment in the future.

4.6.1.3. Cesium-137 Activity of Islands Samples

Table 4-16 show the activity concentration values of ^{137}Cs in the measured soil samples of Islands. It is clearly appearing that the maximum activity concentration of ^{137}Cs is 7.00 Bq/kg and the minimum is 0.05 B/kg with an mean value of 1.204 Bq/kg in soil samples. These values of ^{137}Cs activity concentrations are lower than that measured for the Abu Dhabi region. It is also lower than or comparable for values that reported in soils from other countries like Pakistan (1.6 Bq/kg) (Rafique, 2014), from Palestine (2.8 Bq/kg) (Abu Samreh *et al.*, 2014).

4.6.1.4. Maximum Activity Concentrations of Islands Soil Samples

All the maximum activity concentration values presented in Table 4-17 for the terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the soil samples of the coastal area of the Abu Dhabi Emirate, were found to be 44.43, 16.44 and 488.69 Bq/kg respectively. These values are

higher than the world mean (35 and 400 Bq/kg for ^{226}Ra and ^{40}K respectively) and lower than the world mean for ^{232}Th (30 Bq/kg) (UNSCEAR, 2000).

Table 4-17 The maximum Activity concentrations observed for ^{226}Ra, ^{232}Th , ^{40}K and ^{137}Cs ± 1σ uncertainties for Islands soil samples

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
S70	---		---	7.99	±	0.39	316.20	±	15.8	---		---
S71	44.43	±	2.22	---		---	---		---	---		---
S72	---		---	---		---	---		---	7.00	±	0.35
S76	36.96	±	1.84	---		---	---		---	6.26	±	0.31
S78	---		---	16.44	±	0.82	488.69	±	24.4	---		---
	---		---	---		---	---		---	---		---
Mean	16.82			3.68			123.08			1.204		

4.6.2. Results of Shore Sediment Samples of Islands

The activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th, ^{40}K, and the artificial ^{137}Cs ± 1σ uncertainties, in the shore sediments samples of the coastal area of the Islands are presented in Table 4-18. The activity concentration values of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs are given in Bq/kg on a dry weight basis.

Table 4-18 Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in shore sediment samples ± 1σ uncertainties for Islands

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
SS66	10.35	±	0.51	3.16	±	0.15	73.37	±	3.66	0.34	±	0.02
SS67	9.82	±	0.49	3.90	±	0.19	119.77	±	5.98	0.17	±	0.01
SS68	3.84	±	0.19	0.46	±	0.02	16.27	±	0.81	0.49	±	0.02
SS69	28.70	±	1.43	1.63	±	0.08	94.46	±	4.72	0.55	±	0.02
SS70	1.71	±	0.08	0.97	±	0.04	14.33	±	0.72	0.13	±	0.01
SS71	6.09	±	0.30	0.90	±	0.04	25.79	±	1.28	0.22	±	0.01
SS72	9.01	±	0.45	1.63	±	0.08	215.50	±	10.77	0.14	±	0.01
SS73	6.10	±	0.30	2.10	±	0.10	141.16	±	7.05	0.34	±	0.01
SS74	67.60	±	3.38	27.1	±	1.35	188.16	±	9.40	0.29	±	0.01
SS75	22.92	±	1.16	1.74	±	0.08	73.80	±	3.69	0.07	±	0.003
SS76	2.85	±	0.14	1.73	±	0.08	19.88	±	0.99	1.11	±	0.05
SS77	3.32	±	0.16	1.90	±	0.09	25.34	±	1.26	0.20	±	0.01
SS78	7.36	±	0.36	1.90	±	0.09	43.72	±	2.18	0.16	±	0.01
SS79	5.64	±	0.28	0.62	±	0.03	22.48	±	1.12	0.34	±	0.01
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**

Sample Code	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{137}Cs (Bq/kg)
Mean	**13.24**	**3.55**	**76.72**	**0.33**

4.6.2.1. Radium-226 and Thorium-232 in Islands Shore Sediment

The maximum activity concentrations for ^{226}Ra and ^{232}Th are 67.60 and 27.10 Bq/kg whereas their minimum concentrations are 1.71 and 0.46 Bq/kg respectively. The mean activity concentrations values of both ^{226}Ra and ^{232}Th are 13.23 and 4.65 Bq/kg respectively. These results show that the mean activity concentration values of the naturally occurring radionuclides, ^{226}Ra and ^{232}Th, in the collected shore sediment samples from the coastal area of Islands are much lower than the world mean of 35 and 30 Bq/kg for ^{226}Ra and ^{232}Th respectively (UNSCEAR, 2000). As shown in Table 4-18 the maximum activity concentration values of ^{226}Ra and ^{232}Th were found for sites SS74 with activity values of 67.60 Bq/kg for ^{226}Ra and 27.10 Bq/kg ^{232}Th respectively. The value of ^{226}Ra was much higher than of the world mean (35 Bq/kg). Hence, this site should be followed up for continuous assessment (UNSCEAR, 2000). Where the activity value for ^{232}Th (27.1 Bq/kg) is close to the world mean of ^{232}Th (30 Bq/kg). These values are recommended for further investigation in the future.

4.6.2.2. Potasium-40 Activity of Islands Shore Sediment

The activity concentrations of ^{40}K in the shore sediment samples collected from the Islands are represented in Table 4-18. The results indicate that the maximum concentration of ^{40}K is 215.5 Bq/kg and the minimum concentration is 14.33 Bq/kg with an mean value of 76.71 Bq/kg. These results show that the mean and even the maximum activity concentration values of naturally occurring ^{40}K in the collected Islands shore sediment samples are much lower than the world mean of ^{40}K which is 400 Bq/kg (UNSCEAR, 2000).

4.6.2.3. Cesium-137 Activity of Islands Samples

Assessment of ^{137}Cs activity concentrations in this study is considered for ascertain if there has been any fallout of ^{137}Cs in the coastal areas. The results indicate that the presence of ^{137}Cs in the shore sediment is evident for fallout, its maximum and minimum activities were found to be 1.11 Bq/kg and 0.07 Bq/kg, with an mean value of 0.325 Bq/kg, as presented in Table 4-18. These activity values are found to be less than the values from the pre-Chernobyl period cited in the literature for marine sediments from different regions of the world (IAEA, 2006).

4.6.2.4. Maximum Activity Concentrations of Islands Shore Sediment

All the maximum activity concentration values presented in Table 4-19 for the terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the shore sediments samples of the coastal area of the Islands, were found to be 67.6, 27.1 and 215.5 Bq/kg respectively. These values are lower than the world mean which are 35, 30 and 400 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively (UNSCEAR, 2000). Besides, the activity concentration of ^{226}Ra at the site SS74 which is 67.6 B/kg and that activity is approximately twice the value of mean world activity concentration of ^{226}Ra as mentioned before.

Table 4-19 The maximum Activity concentrations observed for ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in shore sediment samples ± 1σ uncertainties

Sample Code	^{226}Ra (Bq/kg)			^{232}Th (Bq/kg)			^{40}K (Bq/kg)			^{137}Cs (Bq/kg)		
SS72	---		---				215.50	±	10.77	---		---
SS74	67.60	±	3.38	27.1	±	1.35	---		---	---		---
SS76	---		---	---		---	---		---	1.11	±	0.05
Mean	13.23		---	4.65		---	76.71		---	0.325		---

4.6.3. Results of Gulf Water Samples of Islands

The activity concentrations of ^{40}K in the Gulf water samples collected from Islands shores are represented in Table 4-20. The results indicate that the maximum activity concentration of ^{40}K is 15.42 Bq/kg and the minimum concentration is 8.08 Bq/kg with an mean value of 11.08 Bq/kg. These results show that the mean activity concentration values of the naturally occurring ^{40}K in the collected Gulf water samples from the Islands are too much lower than the world mean of ^{40}K (UNSCEAR, 2000). This indicates that the transfer of ^{40}K from soil or shore sediment to Gulf water in the Islands is negligible.

Table 4-20 Activity concentrations of ^{40}K in Gulf water samples ± 1σ uncertainties for Islands

Code	Activity Bq L^{-1}	Code	Activity Bq L^{-1}
W47	10.59 ± 0.52	W57	10.40 ± 0.52
W48	8.20 ± 0.41	W58	14.86 ± 0.74
W49	13.63 ± 0.68	W59	8.23 ± 0.41
W50	13.10 ± 0.65	W60	10.45 ± 0.52
W51	13.47 ± 0.67	W61	12.63 ± 0.63
W52	8.25 ± 0.41	W62	9.10 ± 0.45
W53	8.64 ± 0.43	W63	10.40 ± 0.52
W54	15.42 ± 0.77	**Minimum**	**8.08 ± 0.40**
W55	13.24 ± 0.66	**Maximum**	**15.42 ± 0.77**
W56	8.08 ± 0.40	**Mean**	**11.1**

4.6.4. Correlation Coefficient (r) between ^{226}Ra, ^{232}Th and ^{40}K Activities for Islands Samples

The Correlation Coefficient (r) between ^{226}Ra and ^{232}Th activity concentrations for soil and shore sediment samples collected from Islands were studied out. Also, correlation for ^{40}K activity concentrations in soil, shore sediment and Gulf water was performed to show if there is any relationship between these natural radionuclides in transformation and movement due to sea currents in the Gulf and tide waves along the shore. The correlation was determined in respect of that the natural concentrations of ^{226}Ra and ^{232}Th in the Earth's crust are 2.9 and 9.6 ppm, respectively, which corresponds to a specific activity of 36.0 and 39 Bq/kg respectively (UNSCEAR, 2000).

The Correlation Coefficient (r) between ^{226}Ra and ^{232}Th activity concentrations in the collected soil and shore-sediment samples of Islands is depicted in Figures 4-12 and 4-13 respectively. The calculated Correlation Coefficient (r) for ^{226}Ra and ^{232}Th is found to be positive with value of (0.64) for soil samples. The positive and significant Correlation Coefficient value is quite logical, as both have the same terrestrial origin.

The calculated Correlation Coefficient (r) for ^{226}Ra and ^{232}Th is found to be positive with value of (0.90) for shore sediment samples. The positive correlation is quite logical, as both have the same terrestrial origin. The positive and significant Correlation Coefficient value may be attributed to that the radioactivity content in shore sediment depends on the rock type from which the sediment is formed, the atmospheric deposition (dry and wet cycles), seawater flux or currents and the physical and chemical properties of the sediment. All these environmental changes and or factors affect the changes in ^{226}Ra and ^{232}Th activity ratios from soil to sediments in Islands.

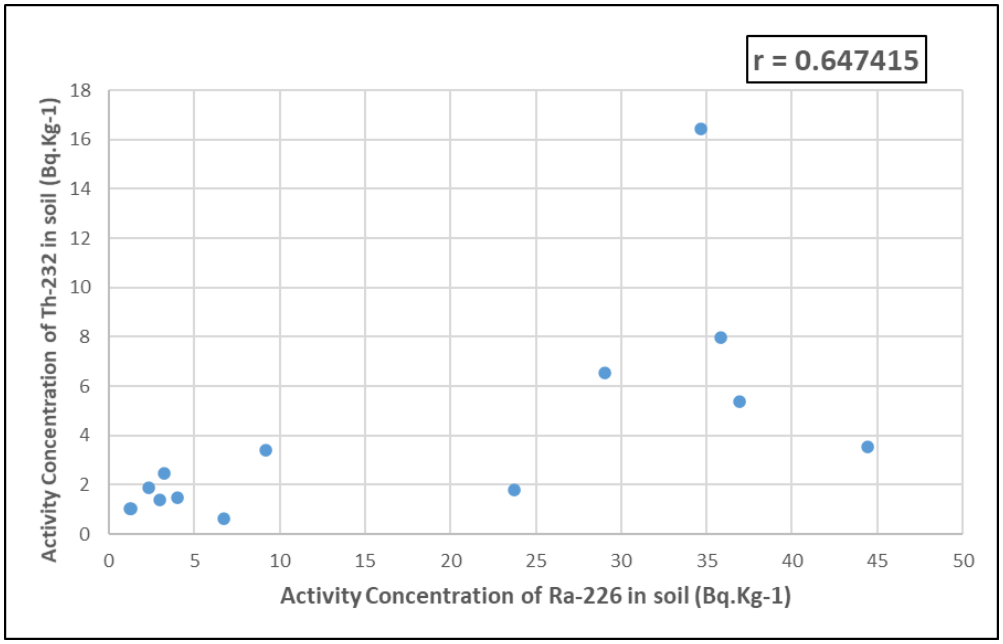

Figure 4-12 The correlation between ^{226}Ra and ^{232}Th in Soils samples from Islands

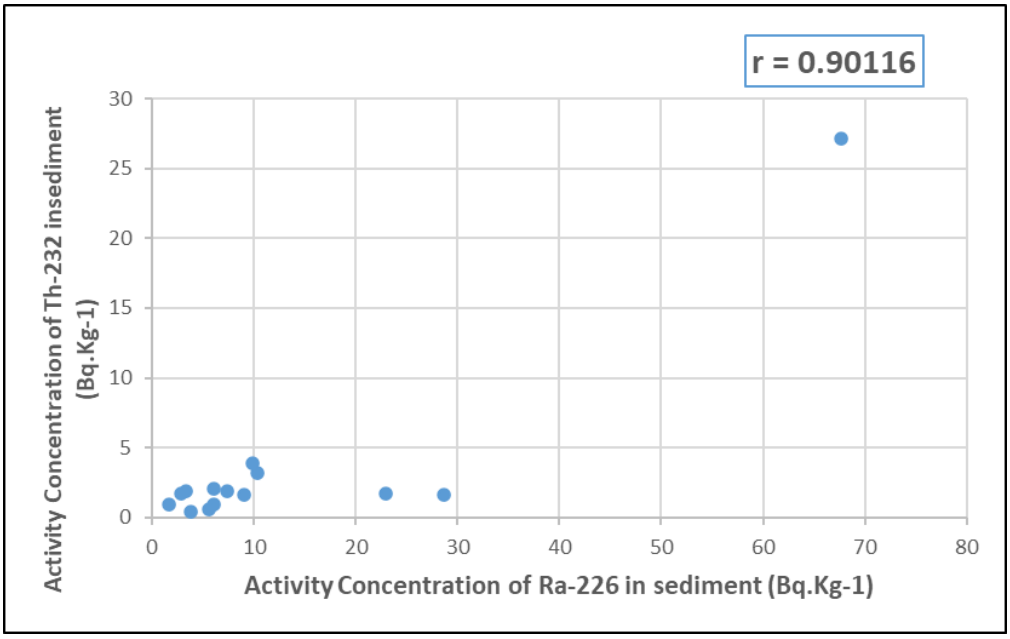

Figure 4-13 The correlation between ^{226}Ra and ^{232}Th in shore sediment samples collected from Islands

The Correlation Coefficient (r) of naturally radioactive Potassium ^{40}K between soil, shore sediment and Gulf water samples for Islands are represented in Figures 4-14, 4-15 and 4-16 respectively. Figure 4-14 illustrates a negative correlation (-0.26) between activity concentration of ^{40}K in soil and shore sediment. This relation shows that there is no relation

between ^{40}K in soil and sediment and its movement from one to another by the effect of tide movement and seawater currents.

On the same way, Figure 4-15 deduces a negative correlation (-.0087) between activity concentrations of ^{40}K in soil and its activity in Gulf water. This relation shows that there is no relation between ^{40}K in soil and Gulf water.

The correlation between activity concentrations of ^{40}K in shore sediment and that in Gulf water for Islands is illustrated in Figure 4-16, the results show a negative correlation (-0.035). This relation shows that there is no relation between ^{40}K in shore sediment and Gulf water.

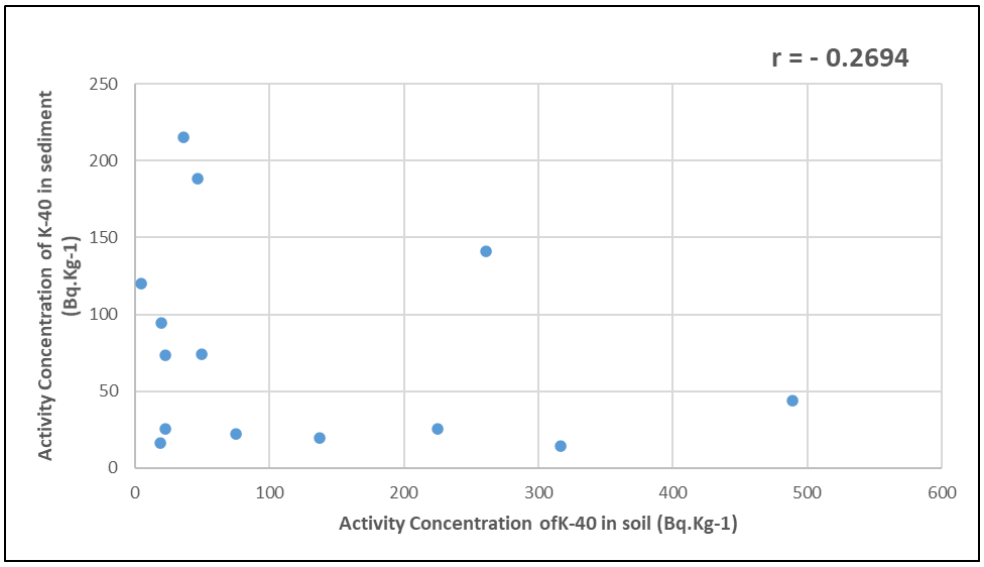

Figure 4-14 The correlation between ^{40}K in soil and shore sediment samples of Islands

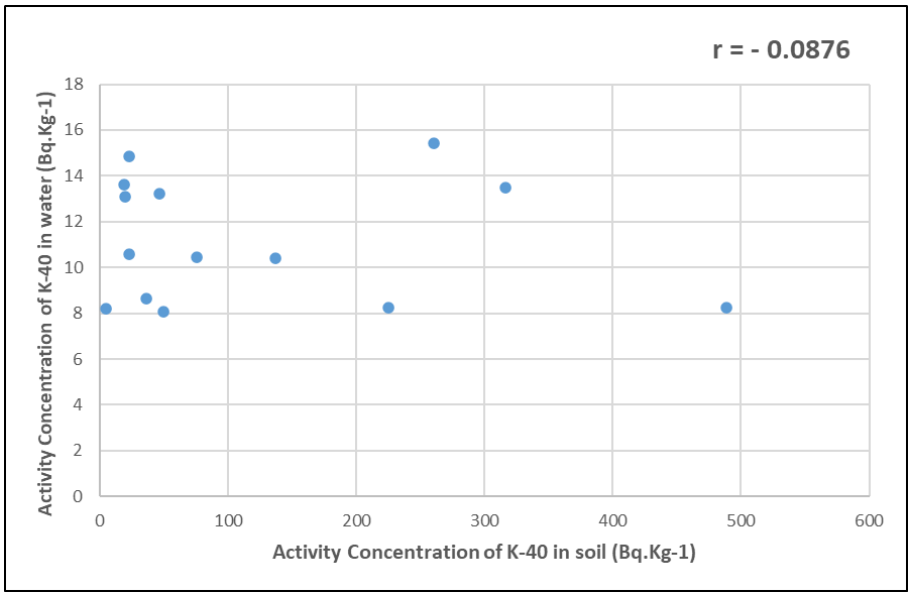

Figure 4-15 The correlation between 40K in soil and Gulf water samples of Islands

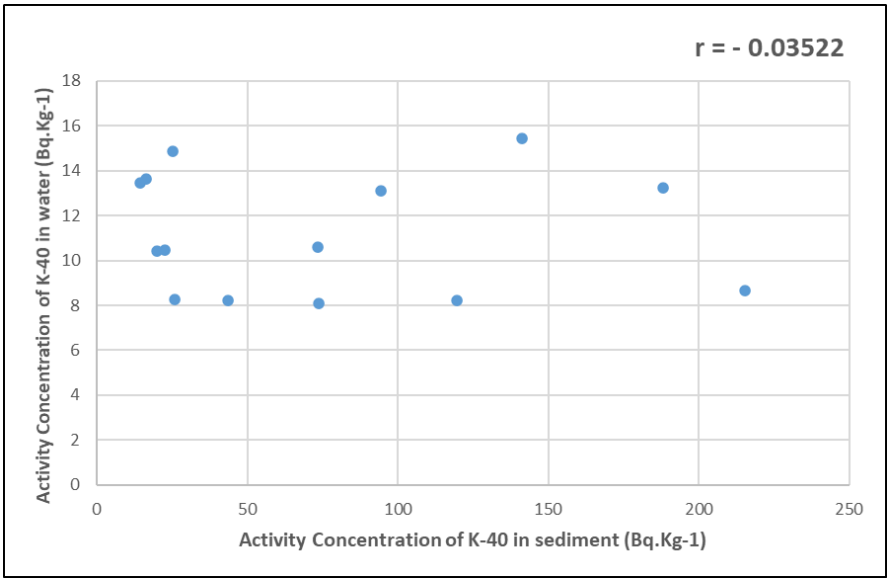

Figure 4-16 The correlation between ^{40}K in shore sediment and Gulf water samples collected from Islands

It is noticeable that there are values for the results that may seem to be outliers' values, but they are few compared to the number of samples that were measured, in addition to the fact that these values did not exceed the global average concentrations of natural radioactive elements. Comparing this study results with the results of nearby countries shows, as we mentioned earlier, that the concentration levels obtained in this study are lower than the concentration levels in those countries. the slight variation in the radioactivity content in soil samples may also be explained by the variations in soil type, formation, and transport processes due to changes in water currents in the Gulf and along water near the shore for a long period of time (Baeza *et al*, 1995; Belivermis *et al*, 2010).

These outlier values may influence Correlation Coefficient (r) by obtaining a negative relationship in some cases, but we cannot rule out these results. On the other hand, the Correlation Coefficient (r) relationship that we sought to obtain is an additional and directing factor that may explain to us the relationship between the concentrations of natural radioactive elements in soil and sediments and Water, but it is not the main objective of this study, so a detailed study of these areas with relatively high levels is required in the future.

4.6.5. Radiation Dose Assessment Calculation Results for Island Samples

The assessment of the potential exposure of an individual to radioactivity present in the soils and the shore sediments of the Islands has been carried out utilizing different indices. They are calculated using the previous equations as follow.

4.6.5.1. Radium Equivalent (Ra_{eq}) calculated Values

The radium equivalent activities are determined for the soil and shore sediment samples for the Islands coast and presented in Tables 4-21 and 4-22. The results indicate that the radium equivalent activities of soil are higher than that of the shore sediment in most of the collected samples from the shores of the Island. The radium equivalent activities of soil samples are ranged from 3.1 to 69.4 Bq/kg with an mean of 21.58 Bq/kg. While for the shore sediment samples it ranges from 4.1 to 119.4 Bq/kg with an mean value of 23.67 Bq/kg, as shown in Table 4-22. These values are much lower than the world limit of 370 Bq/kg, as reported by UNSCEAR (2000), and are also comparable with previously reported values in many neighbouring countries (Abd El Wahab & El Nahas, 2013; Al-Ghamdi *et al*., 2016; El-Taher & Madkour, 2013).

Table 4-21 Radiation Hazard Indices from soil samples of Islands

Sample Code	R_{aeq} (Bq/kg)	D (nGy/h)	AED (mSv/y)	Hex	I_γ	I_α
S66	44.6	21.0	0.03	0.12	0.02	0.01
S67	25.3	12.8	0.02	0.07	0.01	0.01
S68	18.7	9.0	0.01	0.05	0.02	0.01
S69	19.0	9.3	0.01	0.02	0.02	0.01
S70	6.6	3.2	0.00	0.01	0.26	0.18
S71	3.1	1.4	0.00	0.02	0.24	0.22
S72	6.3	3.0	0.00	0.01	0.04	0.02
S73	4.1	2.1	0.00	0.19	0.22	0.15
S74	69.4	34.2	0.04	0.18	0.04	0.02
S75	65.2	31.0	0.04	0.02	0.10	0.12
S76	9.3	4.6	0.01	0.15	0.20	0.18
S77	56.6	27.9	0.03	0.03	0.03	0.03
S78	9.4	4.7	0.01	0.08	0.36	0.17
S79	29.7	13.4	0.02	0.15	0.07	0.05
World Limits	**≤370.0**	**76.0**	**<0.09**	**≤1**	**≤1**	**≤1**

Table 4-22 Radiation Hazard Indices from Shore Sediment for Islands

Sample Code	R_{aeq} (Bq/kg)	D (nGy/h)	AED (mSv/y)	Hex	I_γ	I_α
SS66	20.0	9.7	0.01	0.06	0.07	0.05
SS67	23.8	11.9	0.01	0.07	0.09	0.05
SS68	5.6	2.6	0.00	0.02	0.02	0.02
SS69	37.6	17.4	0.02	0.10	0.14	0.14
SS70	4.1	2.0	0.00	0.01	0.02	0.01
SS71	9.2	4.3	0.01	0.03	0.03	0.03
SS72	26.4	14.2	0.02	0.08	0.11	0.05
SS73	19.0	10.1	0.01	0.05	0.08	0.03
SS74	119.4	50.9	0.07	0.33	0.42	0.34
SS75	30.6	14.1	0.02	0.08	0.11	0.11
SS76	6.7	3.2	0.00	0.02	0.02	0.01
SS77	7.8	3.8	0.00	0.02	0.03	0.02
SS78	13.1	6.3	0.01	0.04	0.05	0.04
SS79	8.1	3.8	0.00	0.02	0.03	0.03
World Limits	**≤370.0**	**76.0**	**<0.09**	**≤1**	**≤1**	**≤1**

4.6.5.2. Outdoor Absorbed Dose Rate for Island Samples

The results show that the absorbed dose rate values for soil samples are varied from 1.4 to 34.20 nGy/hr, with an mean value of, 12.68 nGy/hr. Whereas, these values for shore sediment samples are varied from 2.0 to 50.9 nGy/hr., with an mean value of 11.09 nGy/hr. These results indicate that the Absorbed Dose Rate values for shore sediment are close to that of soil. Whereas, the mean absorbed dose rate from the soil samples (12,68 nGy/hr.) is slightly higher than that of the sediment (11.09 nGy/hr.). In all cases, the Absorbed Dose Rate of both of soil and shore sediment are found to be lower than the world mean value of the absorbed dose rate which is 76.0 nGy/hr., and as reported in the UNSCEAR (2000).

4.6.5.3. Annual Effective Dose (AED) Calculated Results

To estimate the Annual Effective Dose rates to the human body, 0.7 and 0.2 Sv/year were used for conversion factor and the outdoor occupancy factor respectively as published by the UNSCEAR (2000). The Annual Effective Dose (AED) for soil and shore sediment of the Islands are listed in Tables 4.21 and 4.22. The results show that the AED values for soil samples ranged from 0.0 to 0.04 mSv/year, with a mean of 0.022mSv/year. While, for the shore sediment samples, the Annual Effective Dose (AED) varied from 0.0 to 0.07 mSv/year., with a mean value of, 0.02 mSv/year. These results indicate that Annual Effective Dose of soil is approximately the same as that of the shore sediment for Islands and both are lower than the world mean Annual Effective Dose (0.09 mSv/year) from outdoor terrestrial gamma radiation (UNSCEAR, 2000).

4.6.5.4. External Hazard Index (Hex) calculated Results

It is noticed that the mean values of the external hazard index for soils and sediments are 0.078 and 0.066 respectively. The value of this index must be less than unity in order to consider the radiation hazard insignificant. Since the values of the study area (Islands) are less than unity, therefore, these regions are assumed to be safe for population and inhabitants (European Commission, 1999). But also, there are some locations, as mentioned earlier, which should be subjected for following up assessment of the activity concentration values of the natural radionuclides to assure safety for different activities.

4.7. Comparison of Activities and Hazard Indices for the Three Regions

The three regions (Abu Dhabi, Dubai & Northern Emirates and Islands) results of analysis and calculations were compared to each other and given in the following tables and 3D figures. The comparison was carried out for soil, shore sediments and water samples. The correlation was also depicted and presented in this section.

4.7.1. Mean Activity of Soil for the Three Regions

The comparison of measured mean activity concentrations results for ^{226}Ra, ^{232}Th, ^{40}K, ^{137}Cs with the world mean for soil samples (UNSCEAR, 2000) are given in Table 4-23 and presented in the Three Dimensions cylindrical shapes; Figures 4-17, 4-18, 4-19 and 4-20. The minimum, maximum and mean are presented in the following table.

Table 4-23 The mean activity of soil for the three studied regions compared with the world mean

Region	^{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
Mean	**16.68**			**4.09**			**113.74**			**0.78**		
Dubai and the 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
Mean	**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
Mean	**16.83**			**3.93**			**123.08**			**1.20**		
World Mean	**35**			**30**			**400**			**---**		

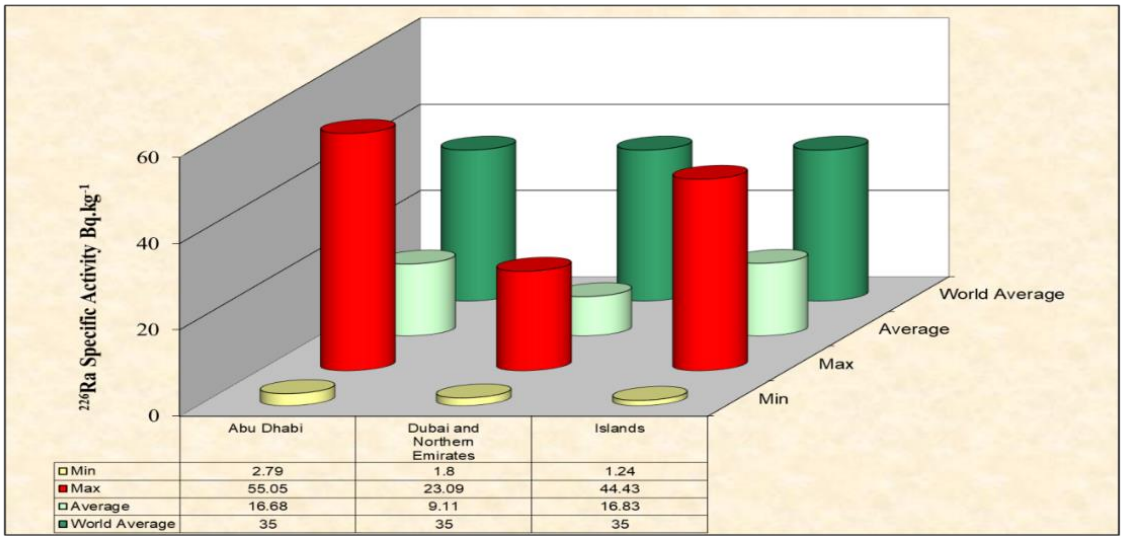

Figure 4-17 The mean ^{226}Ra activity of soil for the three studied regions compared with the world mean

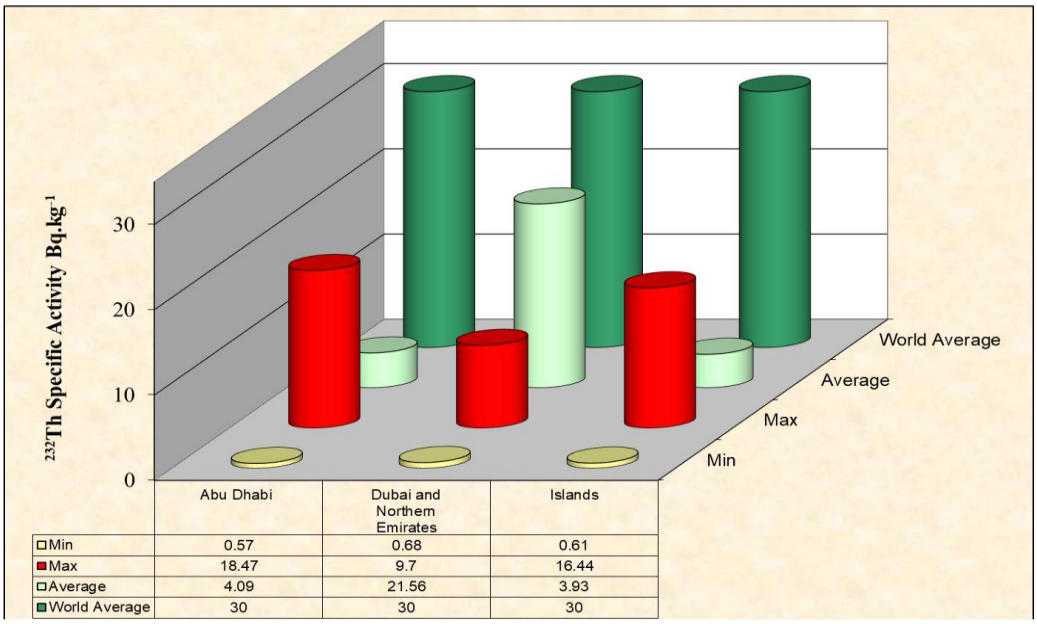

Figure 4-18 The mean ^{232}Th activity of soil for the three studied regions compared with the world mean

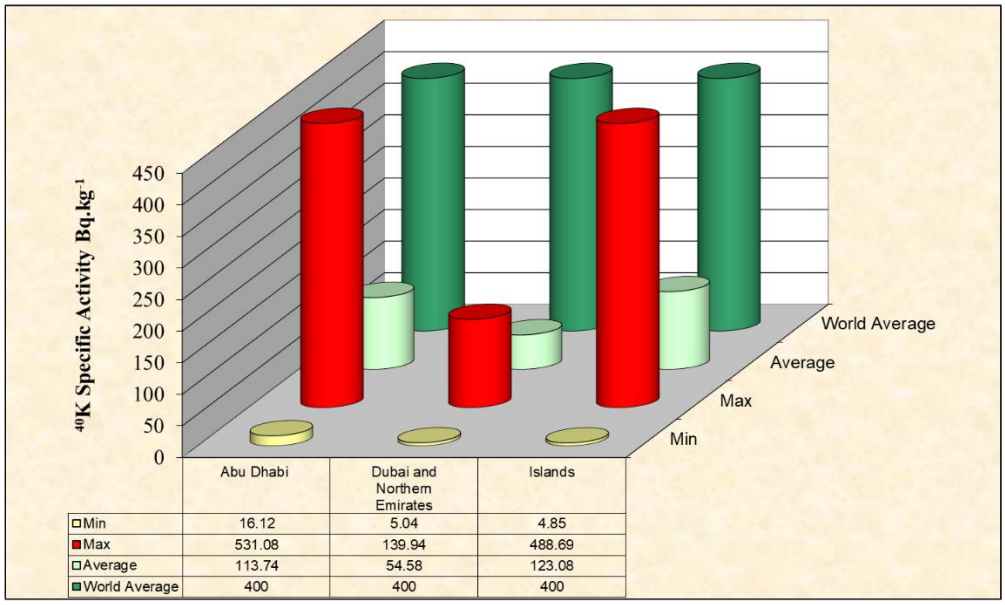

Figure 4-19 The mean ^{40}K activity of soil for the three studied regions compared with the world mean

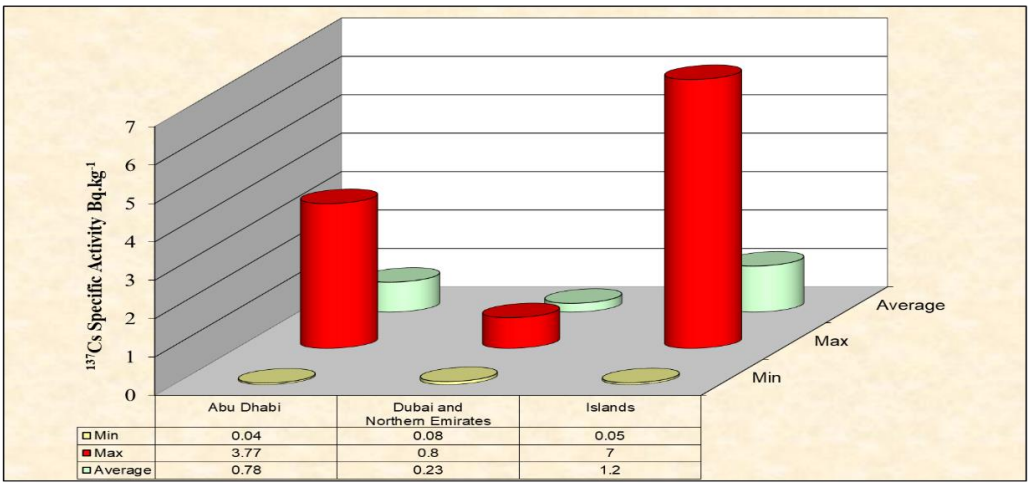

Figure 4-20 The mean ^{137}Cs activity of soil for the three studied regions

4.7.2. Correlation Coefficient (r) between ^{232}Th and ^{226}Ra Activities for Three Regions

The Correlation Coefficient (r) between ^{232}Th and ^{226}Ra activity in soil for the three regions is given in Figure 4-21 with positive and relatively insignificant correlation coefficient (r) of (0.607).

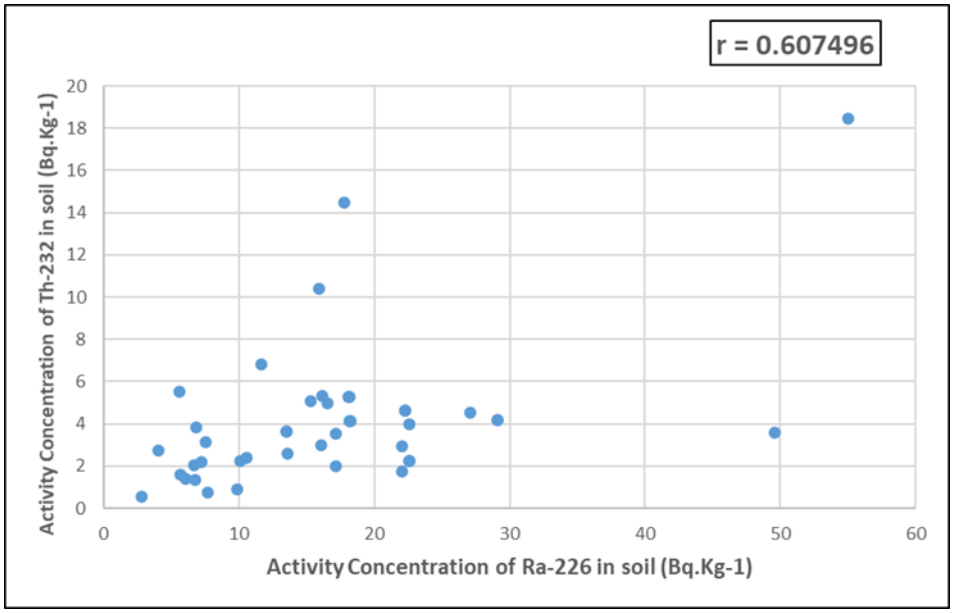

Figure 4-21 The correlation of ^{232}Th and ^{226}Ra activity of soil for the three regions

4.7.3. Mean Activity of Shore Sediment for the Three Regions

The comparison of measured mean activity concentrations observed for ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs and the world mean (UNSCAR, 2000) in shore sediment samples is given in Table 4-24 and presented in the Three Dimensions cylindrical shapes; Figures 4-22, 4-23, 4-24 and 4-25.

Table 4-24 The mean activity of shore sediment samples for the three regions compared with the world mean

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
Mean	**10.6**			**3.35**			**121.75**			**0.45**		
Dubai and the 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
Mean	**6.29**			**2.41**			**61.48**			**0.26**		
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

Sample Code	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{137}Cs (Bq/kg)
Mean	13.24	3.55	76.72	0.33
World Mean	**35**	**30**	**400**	**---**

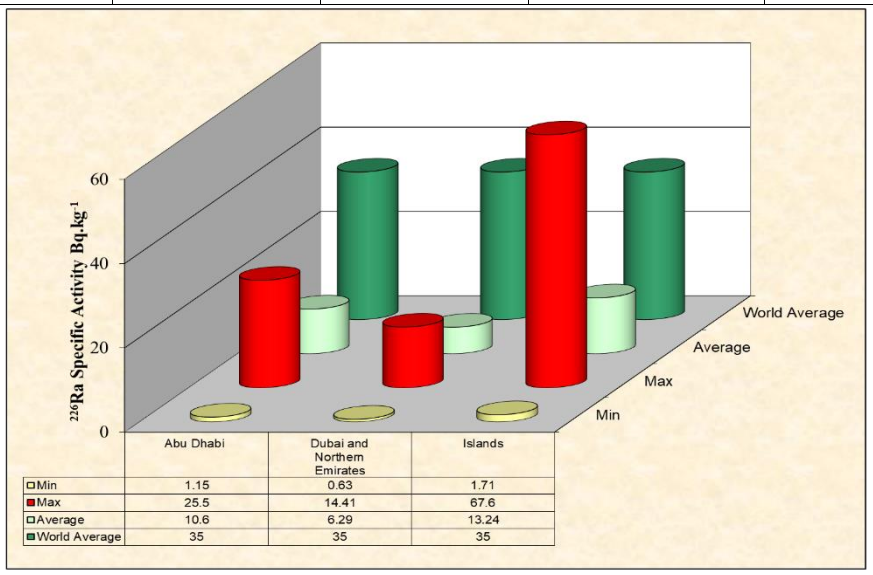

Figure 4-22 The activity of ^{226}Ra of shore sediments of the three regions compared with the world mean

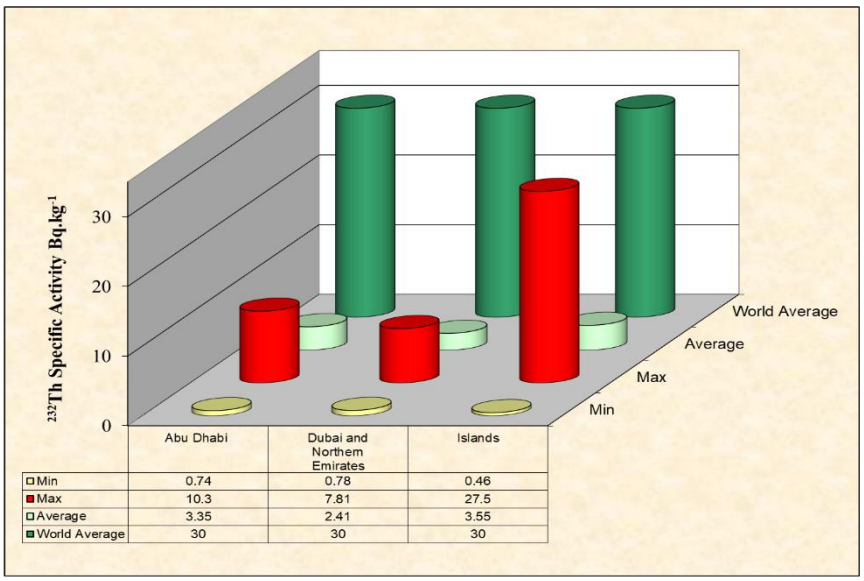

Figure 4-23 The activity of ^{232}Th in the three studied regions compared with the world mean

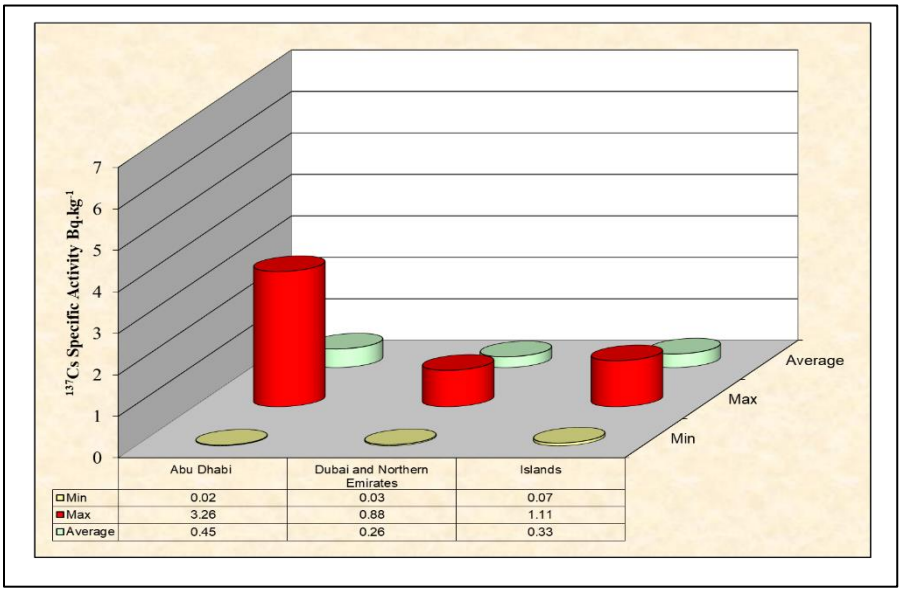

Figure 4-24 The activity of ^{137}Cs of shore sediments in the three studied regions compared with the world mean

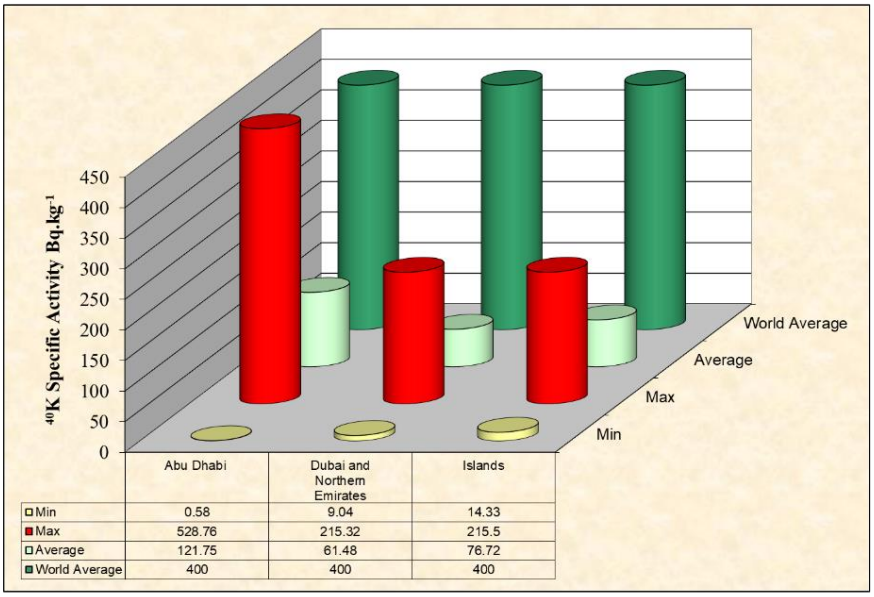

Figure 4-25 The activity of ^{40}K in Shore Sediments samples of the three regions compared with the world mean

4.7.4. Correlation Coefficient (r) between, ^{226}Ra and ^{232}Th Activities for Three Regions

The Correlation Coefficient (r) between ^{232}Th and ^{226}Ra activity in shore sediments for the three regions is given in Figure 4-26 with a positive correlation coefficient (r) of 0.786 was observed in this case.

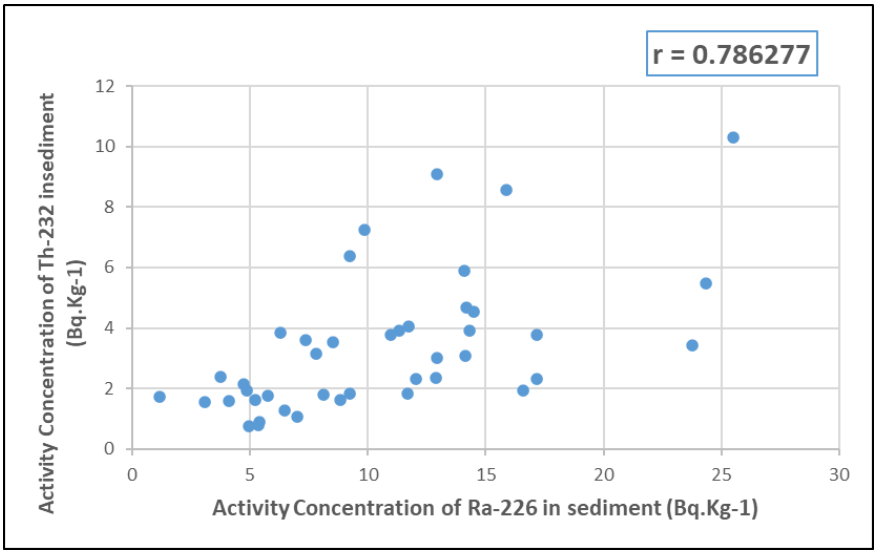

Figure 4-26 The correlation between ^{226}Ra and ^{232}Th activity of the shore sediments samples in three regions

4.7.5. Mean Activity of Gulf Water for the Three Regions

The comparison of the measured mean activity concentrations observed for ^{40}K in Gulf water samples is given in Table 4-25 and Figure 4-27.

Table 4-25 Comparison of the ^{40}K activity in the water of the three regions

Activity Bq L^{-1}	Abu Dhabi	Dubai and the 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
Mean	11.33	9.205	11.1

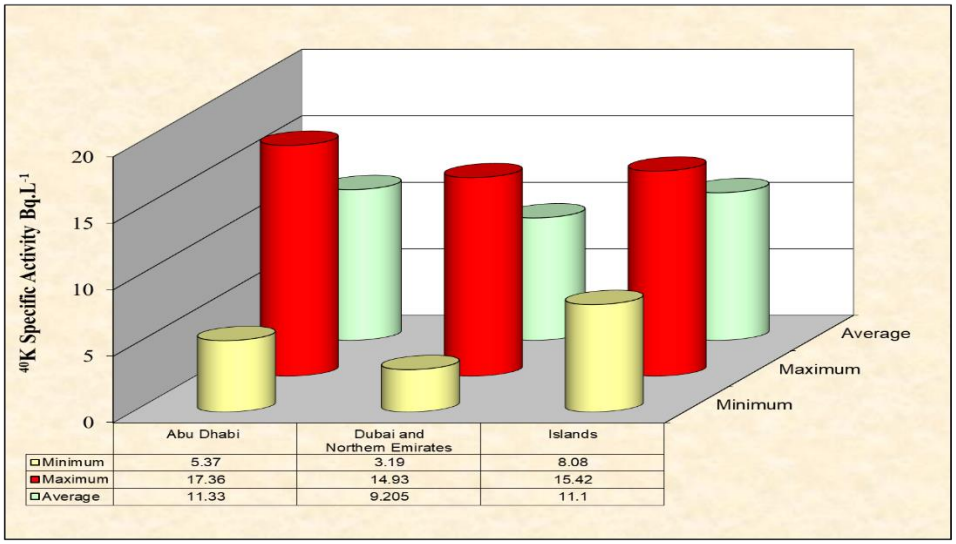

Figure 4-27 Comparison of the activity of ^{40}K in the water of three studied regions

Chapter 5 Summary, Conclusions and Recommendations

5.1. Summary

Based on the energy of the electromagnetic radiations, they may be classified into ionizing and non-ionizing radiations. They are ionizing when the photon possesses enough energy to remove an electron from an atom (or molecule), i.e. to ionize the atom, otherwise they are non-ionizing.

Naturally occurring radioactive materials, NORMs, can be found almost everywhere, in soil, air, public water supplies, oil and even radioactive potassium40K in our bodies, therefore NORMs always has been a part of our world and hence sources of radioactive isotopes in the environment. Humans are exposed to natural environmental radiation and the mean exposure is governed by United Nations UNSCEAR reports whereby international recognised exposure limits are set. The main parts of the natural radioactivity in soils derive from the members of the radioactive decay series of 238U and ^{232}Th, along with 40K. Radiological protection of humans from natural radiation is important, thus measurement of soil radioactivity is essential. The earth's most important ionising radiation comes from natural decay of ^{238}U, ^{232}Th and ^{235}U which contributes almost 83% of the collective ionising radiation while the rest comes from ^{40}K.

This study focuses mainly on establishing a radiological baseline measurement in the UAE. . The results of this research project will be a first step in addressing the need of the UAE for a nationwide radiological surveillance program. Environmental analysis is one of the vital instruments to assess the impact of man-made activities on the environment, and the methods of determining radioactivity levels are well documented. The country has already begun to operate the nuclear power reactors of Barakah NPP. The first unit was connected to the grid in August 2020. It reached 100% power in December 2020 and entered commercial operation in April 2021.

Here is a brief summary of the first four chapters of this study., An introduction into radiation, series and non-series NORMs and anthropogenic radioisotopes different sources as well as the theoretical and scientific basis of the ionising radiation, especially gamma rays were discussed. Following that a detailed search into literature on the analysis of regional and international environmental samples using different non-destructive and destructive techniques were investigated giving in details the level of natural and man-made radioactivity levels in environmental matrices also covering the literature of hazard indices values worldwide. Transfer of NORMs or artificial radioisotopes was addressed. Several steps were implemented in experimentation in this study such as collection and preparations

methods of soil, sediment, water samples. The mechanical testing and X-Ray Diffraction analysis (XRD) for mineralogy of the samples were listed. Also, the quality assurance and quality control (QA/QC) program, the standard reference materials for validation of the results were presented.

An extensive sampling and measurement scheme has been implemented in this study. For the sake of sampling the UAE was divided into three major areas, Abu Dhabi Emirate region, Dubai and the Northern Emirates region and Islands in the Arabian Gulf regions. The results of mechanical analysis, chemical and physical analysis, XRD and specific activity calculations were presented. results obtained are discussed, interpreted and compared with other national and international world values and limits. The correlations between the results of radioactivity levels of the measured radionuclides $^{238}U/^{226}Ra$, ^{232}Th, ^{40}K and ^{137}Cs of the studied areas are depicted as 3D figures and discussed with their Correlation Coefficients values (r).

5.2. Limitations

There were some limitations and obstacles the team faced while carrying-out sampling strategy and mechanism of this work such as:

i. Sampling of bottom sediment samples due to high water current and depth.
ii. Difficulties to access some sites.
iii. Transportation of the team by air to collect samples from the Islands

5.3. Conclusions

Surveillance monitoring along the United Arab Emirates (UAE) coastal areas and some islands has been carried out to ensure that the radiation levels and doses received to the public are below the authorised national and international limits, as well as providing a base-line data on natural baseline and background radiation in the investigated regions. Soil, shore and bottom sediment and seawater samples were collected from selected locations along the coast and islands as mentioned. The radioactivity was measured by gamma spectrometry using high purity germanium detector and its associated electronics. The activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were investigated and determined in the collected samples. Radiological hazards and risk were assessed through the estimation of radium equivalent activities, the absorbed dose rate from external gamma radiation, the annual effective dose and the external hazard index. Quality assurance and methods validation were established through the efficiency calibration of the detector, the estimation

of uncertainties, the use of blanks, the analysis of standard reference materials and the inter-comparison and proficiency tests. The following major points are concluded:

i. In general, the results obtained in this work cover a wide area along the United Arab Emirates (UAE) coastal areas and can be considered as a baseline radioactivity map for these regions that can be utilised as a preliminary pre-operational map before the operation of the first nuclear power plant (NPP) and effluents control signals and monitor for post-operational mode.

ii. These radioactivity results are also useful to assess any potential threat due to the neighbouring nuclear activities located at the Arabian Gulf.

iii. Validation and verification of the analytical technique parameters used for accurate gamma spectroscopy analysis were perfectly achieved.

iv. Quality control program was precisely applied for confident radioactivity measurements, calculations and results.

v. The SEM/XRF and XRD were carried out for the collected samples and identified their main characteristics and mineralogical structure to be used as a function in the radioactivity content and levels.

vi. The mean specific activity of the natural 226Ra, ^{232}Th, 40K and the artificial, 137Cs 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, 400 Bq/kg for 226Ra, ^{232}Th and 40K respectively).

vii. The mean specific activity of 226Ra, ^{232}Th and 40K and ^{137}Cs in the sediment samples were 9.7, 3.2, 98.6 and 0.4 Bq/kg respectively. 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.

viii. 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.

ix. The radium equivalent (Raeq.) 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 documents.

x. The absorbed dose rate from external gamma radiation from soils and sediments was estimated and the mean values were far below the international recommended limit of 79.0 nGy/hr.

xi. The annual effective dose from the soil and sediment samples was determined and found to have an mean value of 0.02 and 0.01 mSv/yr respectively, which are both far below the world mean value of 0.09 mSv/yr.

xii. 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 were far less than unity, and that keep the radiation hazard insignificant.

xiii. The activity indices (gamma index – alpha index) were also calculated and their values were also found to be below the world limits.

xiv. On the basis of the current study, we may conclude that the results obtained in the investigated soils and coastal sediments are lower than their corresponding reported values in literature and the international reports, and they don't pose any radiological hazards or significant risk to the public.

xv. The radioactivity of the wide studied area can also be useful for radiological monitoring and protection of the UAE territorial and marine boarders and harbours.

xvi. Finally, it can be mentioned and concluded that the survey, measurements analysis and calculations carried out on the coastal boarder and islands of the UAE show natural and man-made radionuclides levels within the national, regional and international radioactivity values and limits. This study is of great importance in emergency planning and for the site monitoring before and after the plant (NPP) operation. The results can be considered as reference to control and evaluate its impact on environment and public.

5.4. Recommendations

We believe we were successful in the assessment of the natural and artificial radioactivity levels in the environment along the coastal borders of the UAE and islands to establish a baseline database of radionuclides concentrations to integrate it in any forthcoming national environmental radiological monitoring programs. We would like to further investigate and so we recommend the following:

i. Establish a national radiological monitoring program that includes yearly sampling from the same sampling points in this study to update radiological

data and readings and record any changes. These data will be crucial to establish national trends in radiation levels.

ii. Expand the program to cover more islands and remote marine sites, that were previously difficult to access, in order to obtain a more accurate and complete radiological picture.

iii. Include the main cities in the national program, so that the scope of the sampling is expanded enough to ensure coverage of the most crowded areas of the population.

iv. Record the radiation doses that can be received by the public, and accordingly provide the necessary instructions to ensure public health.

v. A comprehensive survey and monitoring strategic plan specifically for Barakah site must be carried out. Where large sampling mechanism in the vicinity and around of the Nuclear Power Plants should be established. This plan may include a collection of air, soil, vegetation, ground water, drinking water, bottom sediments, fish, and some other aquatic biota. Using different destructive (such as ICP-MS) and non-destructive techniques for analysis of these samples should also be considered. In-site measurements using portable HpGe spectrometer can also be carried out in parallel to the site sample collection, preparation and analysis in the laboratories. Fixed radiological monitoring stations around the facility (NPPs) are also to be integrated with this comprehensive plan.

vi. The approach of anthropogenic radioisotopes monitoring (e.g. plutonium, strontium, tritium and americium) of the NPPs liquid effluent to the Gulf water are highly recommended. This will be based on collection of large samples (e.g.50 L) and with chemical treatment can be separated to be quantified by different analytical techniques. Such analyses will be a direct function of the operation safety of the facility. Determination of these radionuclides levels reflects and must be identified with the permitted levels for operation license of the facility.

vii. In the framework of health and radiation safety, study the natural radioactivity (i.e., 210Po, 14C and 40K) in the human bodies and tissues of worker and public nearby the NPPs is of vital importance. In addition, the monitoring of the internal pathways and radiation doses due to the effect of these radionuclides has to be considered.

References

Abd El Wahab, M., El Nahas, H. A., (2013) 'Radionuclides measurements and mineralogical studies on beach sands, East Rosetta Estuary, Egypt', *Chinese Journal of Geochemistry*, 32(2), pp. 146 -156

Abdelfattah, M.A., Shahid, S.A., (2007) 'A Comparative Characterization and Classification of Soils in Abu Dhabi Coastal Area in Relation to Arid and Semi-Arid Conditions Using USDA and FAO Soil Classification Systems', Arid Land Research and Management, 21(3), pp. 245 -271.

Abdel-Rahman, M. A. E. and El-Mongy, S. A (2017) 'Analysis of radioactivity levels and hazard assessment of black sand samples from Rashid area, Egypt', *Nuclear Engineering and Technology. Elsevier BV*, 49(8), pp. 1752 -1757.

Abu Samreh, M.M., Thabayneh, K.M., Khrais, F.W., (2014) 'Measurement of activity concentration levels of radionuclides in soil samples collected from Bethlehem Province, West Bank, Palestine', *Turkish Journal of Engineering & Environmental Sciences*, 38 (2), pp. 113 - 125.

Agency for Toxic Substances and Disease Registry ATSDR (2011) 'The priority list of hazardous substances', Agency for Toxic Substances and Disease Registry, Atlanta: ATSDR.

Ajibode M.O., Avwiri G.O. and Agbalagba E.O. (2013) 'Evaluation of radiation hazards indices in an oil mineral lease (oil block) in Delta state, Nigeria', *International Journal of Engineering and Applied Sciences*, 4(2), pp. 104 -121.

Alaamer A.S. (2008) 'Assessment of Human Exposures to Natural Sources of Radiation in Soil of Riyadh, Saudi Arabia', *Turkish J. Eng. Env. Sci.*, 32(2008), pp. 229 -234.

Alaamer, A.S., (2012) 'Measurement of Natural Radioactivity in Sand Samples Collected from Ad-Dahna Desert in Saudi Arabia', *World Journal of Nuclear Science and Technology*, 2(04), pp. 187-191.

Alam, L. and Mohamed, C.A.R. (2011) 'Natural Radionuclide Of ^{210}Po In the Edible Seafood Affected By Coal-Fired Power Plant Industry In Kapar Coastal Area Of Malaysia', *Environmental Health*, 10(43), pp.2-10 [Online].Available at: *https://doi.org/10.1186/1476-069X-10-43*.

Al-Ghamdi, H., Al-Muqrin, A., El-Sharkawy, A., (2016) 'Assessment of natural radioactivity and ^{137}Cs in some coastal areas of the Saudi Arabian gulf', *Marine Pollution Bulletin*, 104(2016), pp. 29 33.

Al-Ghorabie, F.H.H., (2005) 'Measurements of environmental terrestrial gamma radiation dose rate in three mountainous locations in the western region of Saudi Arabia', *Environmental Research*, 98(2), pp. 160-166.

Al-Kheliewi, A.S., Shabana, E.I. Activity concentration of some anthropogenic radionuclides in the surface marine sediments near the Saudi coast of the Arabian (Persian)

Gulf. J Radioanal Nucl Chem 274, 207–212 (2007). https://doi.org/10.1007/s10967-006-6863-7

Al-Hassani S. R., Elbaz A. E., El-Mongy S. A. and Dennis, J. (2004) 'Analysis and Evaluation of Uranium and Thorium in Marine Sediments around Abu-Dhabi Island of UAE', *Proceedings of the VII Radiation physics & protection conference, Ismaillia , Egypt*, 27 -30 Nov.

Al-Zahrani J.H. (2017) 'Estimation of natural radioactivity in local and imported polished granite used as building materials in Saudi Arabia', *Journal of Radiation Research and Applied Sciences,* 10(2017), pp. 241-245.

Amanjeet, Ajay Kumar, Suneel Kumar, Joga Singh, Parminder Singh, and Bajwa, B.S. (2017) 'Assessment of natural radioactivity levels and associated dose rates in soil samples from historical city Panipat, India', *Journal of Radiation Research and Applied Sciences,* 10, pp. 283 -288.

Arafat, A.A., Salama, M.H.M., El-Sayed, S.A. and Elfeel, A.A. (2017) 'Distribution of natural radionuclides and assessment of the associated hazards in the environment of Marsa Alam-Shalateen area, Red Sea coast, Egypt', *Journal of Radiation Research and Applied Sciences*, 10(3), pp. 219-232.

Avwiri G. O. (2005) 'Determination of Radionuclide Levels in Soil and Water around Cement Companies in Port Harcourt', *J. Appl. Sci. Environ. Mgt.,* 9(3), pp. 27 -29.

Avwiri, G.O., Osimobi, J.C and Agbalagba, E.O. (2013) 'Evaluation of natural occurring radionuclide variation with lithology depth profile of UdI and Ezeagu local government areas of Enugu state, Nigeria state, Nigeria', *Journal of Radiation Research and Applied Sciences,* 8(2), pp. 216 -220.

Baeza, A., Del Rio, M., Jimenez, A., Miro, C., and Paniagua, J., (1995) 'Influence of Geology and Soil Particle Size on the Surface-Area/Volume Activity Ratio for Natural Radionuclides', *Journal of Radioanalytical and Nuclear Chemistry,* 189(2), pp. 289–299.

Belivermis, M., Kiliç, N., Cotuk, Y., Topcuoğlu, S., (2010) 'The Effects of Physicochemical Properties on Gamma Emitting Natural Radionuclide levels in the Soil Profile of Istanbul', *Environmental Monitoring and Assessment,* 163(1-4), pp. 15–26.

Beresford N.A., Appleton J.D., Barnett C.L., Bescoby M.W., Breward N., Jones D.G., MacKenzie A.C., Scheib C., Thørring H. and Wood M.D. (2009) 'Assessment of naturally occurring radionuclides around England and Wales', *Radioprotection,* 44(5), pp. 629 -634.

Beretka, J. and Mathew, P. J. (1985), Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys. 48, 87–95.

Bernd Franke (2007) *A review of Environmental Monitoring for Radionuclides in Air at the Sandia National Laboratory,* Heidelberg: Institute for Energy and Environmental Research.

Blanchard, R.L., Hahne, R.M., Kahn, B. and Whittaker, E. (1985) 'Radiological Sampling and Analytical Methods for National Primary Drinking Water Regulations', *Health Physics,* 47(5), pp. 587 -600 [Online]. Available at: *DOI: 10.1097/00004032-198505000-00003*.

Bolıvar, J.P., Garcıa-Tenorio, R. and Garcıa-Leon, M. (1995) 'Enhancement of Natural Radioactivity In Soils And Salt-Marshes Surrounding A Non-Nuclear Industrial Complex', *The Science of the Total Environment,* 173/174(1 December 1995), pp. 125 -136.

Bou-Rabee, F. (1997) 'Soil Radioactivity Atlas of Kuwait', *Environment International,* 23(1), pp. 5 -15 [Online]. Available at: *https://doi.org/10.1016/S0160-4120(96)00073-6*.

Bowen, H. J. M. (1979) *Environmental Chemistry of the Elements*, London: Academic Press.

Branko Petrinec, Marko S. trok, Zdenko Franic, Borut Smodis and Dijana Pavic Hamer (2013) 'Radionuclides in the Adriatic Sea and related dose rate assessment for marine biota', *Radiation Protection Dosimetry,* 154(3), pp. 320 -330.

Chacha, R. (2014) *Method for Analysing Soil Samples For Mineral Composition Using XRD*, Nairobi: World Agroforestry Center ICRAF.

Chena S.B., Zhua Y.G., Huc Q.H. (2005) 'Soil To Plant Transfer Of U238, Ra226 And Th232 On A Uranium Mining-Impacted Soil From Southeastern', *China Journal of Environmental Radioactivity,* 82(2), pp. 223 -236.

Chieco, Nancy A. (1997) 'The Procedures Manual of The Environmental Measurements Laboratory HASL-300 28th Ed', New York: U.S. Department of Energy.

Christoudias, T., Proestos, Y. & Lelieveld, J. (2014) 'Atmospheric Dispersion of Radioactivity from Nuclear Power Plant Accidents: Global Assessment and Case Study for the Eastern Mediterranean and Middle East', *Energies,* 2014(7), pp. 8338 -8355 [Online]. Available at: *doi:10.3390/en7128338*

Currie, L.A. (1984) *Lower Limit of Detection: Definition and Elaboration of a Proposed Position for Radiological Effluent and Environmental Measurements NUREG CR-4007,* Washington, D.C.: U.S. Nuclear Regulatory Commission.

E. Gomez, F. Garcias, M. Casas and V. Cerda (1994) Analysis of environmental radioactivity in direct exposure pathways, *J. Environmental Science and Health,* A29 (10), pp. 2169-2175.

El Mamoney, M.H., Khater, A.E.M., (2004) 'Environmental Characterization and Radio-Ecological Impacts Of Non-Nuclear Industries On The Red Sea Coast', *Journal of Environmental Radioactivity,* 37(2), pp. 151-168.

El Samad, O., Alayan, R., Baydoun, R. and Zaidan, W. (2012) 'Radiation Baseline Levels in Lebanon Environment: Environmental Survey And Public Dose Assessment', *Lebanese Science Journal,* 13(2), pp. 37 -48.

El-Aydarous, A., (2007) 'Gamma radioactivity levels and their corresponding external exposure of some soil samples from Taif Governorate, Saudi Arabia', *Global journal of environmental research,* 1(2), pp. 49 -53.

Ellison S. L., Williams, A., (2000). 'Eurachem/CITAC Guide CG4 Quantifying uncertainty in analytical measurement'. EURACHEM/CITAC.

El-Sayed, N.A.E.K. (2014) *Studying of Naturally Occurring Radionuclides for Some Environmental Samples and Its Hazardous Effects*, Master Thesis, Faculty of Science: Fayoum University.

El-Tahawy, M.S., Farouk, M.A., Ibrahiem, N.M., El-Mongey, S.A.M., (1994) 'Natural And Artificial Radionuclides In The Suez Canal Bottom Sediments And Stream Water', *Radiation Physics and Chemistry,* 44(1-2), pp. 87-89.

El-Tahawy, M.S.; Farouk M.A.; Hammad F.H. and Ibrahiem N.M. (1992) 'Natural Potassium as Standerd Source for the Absolute Efficiency Calibration of Germanium Detectors', *Nucl. Sci. J.,* 29(5), pp. 361 -363.

El-Taher A., "Assessment of natural radioactivity levels and radiation hazards for building materials used in Qassim area Saudi Arabia", Rom. Journ. Phys., Vol. 57, No. 3-4, P. 726-735, Bucharest, (2012).

El-Taher, A., And Madkour, H.A., (2013) 'Texture and Environmental Radioactivity Measurements of Safaga Sand Dunes', *Chinese Journal of Geochemistry,* 24(1), pp. 35 -41.

Environmental Protection Agency U.S. EPA (2002) *Guidance in Choosing a Sampling Design for Environmental,* Washington, DC: United States Environmental Protection Agency.

European Commission EC, (1999) *Radiation protection 112, Radiological Protection Principles concerning the Natural Radioactivity of Building Materials*, Luxembourg: Directorate - General for Environment and Nuclear Safety and Civil Protection.

Farouk M.A. and Al-Soraya A.M. (1982) 'Ra-226 as a Standard Source For Efficiency Calibration of Ge(Li) Detectors', *Nuclear Instruments and Methods,* 200(2-3), pp. 593-595.

Ferrari, F., and Szuszkiewicz, E. (2009) 'Cosmic Rays: A Review for Astrobiologists', *Astrobiology,* 9(4), pp. 413 -436 [Online]. Available at: *Retrieved from https://link-gale-com.uaeu.idm.oclc.org/apps/doc/A202126011/AONE?u=nml_uae&sid=AONE&xid=72f2e1e6* (Accessed: 2 June 2020.).

Gascoyne, M. and Larocque, J. P. A. (1984) 'A Rapid Method Of Extraction Of Uranium And Thorium From Granite For Alpha Spectrometry', *Nuclear Instruments and Methods in Physics Research,* 223(2-3), pp. 250 -252.

Goddard, CC. (2002) 'Measurement of outdoor terrestrial gamma radiation in the Sultanate of Oman', *Health Phys*., 82(6), pp. 869-74.

Gordon R. Gilmore (2008) *Practical Gamma-ray Spectrometry*, 2nd edn., England: John Wiley & Sons.

Grzegorz Poreba, Andrzej Bluszcz, Zbigniew Snieszko (2003) 'Concentration and Vertical Distribution Of ^{137}cs In Agricultural and Undisturbed Soils from Chechlo And Czarnocin Areas', *GEOCHRONOMETRIA,* 22, pp. 67 -72.

Harb S., El-Kamel A. H., Zahran E. M., Abbady A., and Ahmed F.A. (2015) 'Assessment of Agriculture Soil Primordial Radionuclide Concentrations in Aden Governorate South Of Yemen Region', *International Journal of New Horizons in Physics,* 2(2), pp. 81 -86.

Harb S., El-Kamel A.H., Zahran A.M., Abbady A., and Ahmed F.A. (2014) 'Assessment of Natural Radioactivity in Soil and Water Samples from Aden Governorate South Of Yemen Region', *International Journal of Recent Research in Physics and Chemical Sciences* , 1(1), pp. 1 -7.

Haridasan, P.P., Paul, A.C. and Desai, M.V.M. (2001) 'Natural Radionuclides In The Aquatic Environment Of A Phosphogypsum Disposal Area', *Journal of Environmental Radioactivity*, 53(2), pp. 155 -156.

Hong G., Baskaran M., Lee H., Kim S. (2008) 'Sinking Fluxes of Particular U–Th Radionuclides In The East Sea (Sea Of Japan)', *Journal of Oceanography*, 64(2), pp. 267 - 276.

International Atomic Energy Agency IAEA (1989) *Measurement of Radionuclides in Food and the Environment Technical Reports Series No. 295*, Vienna: IAEA.

International Atomic Energy Agency IAEA (2005a) *Country Nuclear Fuel Cycle Profiles - Second Edition, Technical Reports Series No. 425*, Vienna: IAEA.

International Atomic Energy Agency IAEA (2005b) *Worldwide marine radioactivity, studies (WOMARS), Radionuclide levels in oceans and seas IAEA-TECDOC-1429*, Vienna: IAEA.

International Atomic Energy Agency IAEA (2006) *Environmental Consequences Of The Chernobyl Accident And Their Remediation: Twenty Years Of Experience*, Vienna: IAEA.

International Atomic Energy Agency IAEA (2013) *Nuclear Fuel Cycle Objectives, Nuclear Energy Series No. NF-O,* Vienna: IAEA.

International Atomic Energy Agency IAEA (2014) *Seven Things to Know About Radioisotopes, IAEA Bulletin 55,* Vienna: IAEA.

International Atomic Energy Agency IAEA (2019) *Guidelines on Soil And Vegetation Sampling For Radiological Monitoring Technical Reports Series No. 486*, Vienna: IAEA.

International Atomic Energy Agency IAEA (2004b) *Quality System Implementation for Nuclear Analytical Techniques, Training Course Series No. 24*. Vienna: IAEA.

International Atomic Energy Agency IAEA, (2004a) *Soil Sampling for Environmental Contaminants, IAEA-TECDOC-1415*. Vienna: IAEA.

International Commission on Radiation Units and Measurements ICRU (1979) *Quantitative Concepts and Dosimetry in Radiology Report 30*. Maryland: ICRU Publications' office.

International Organization for Standardization (2005) General requirements for the competence the resting and calibration laboratories ISO-17025. Second edition.

Islam A., Begum A., Yeasmin S., Sultana M.S. (2014) 'Assessment of Dose Due To Natural Radio-Nuclides In Vegetables Of High Background Radiation Area In South-Eastern Part Of Bangladesh', *International Journal of Radiation Research,* 12(3), pp. 271 -275.

Ivanovich M., Latham A.G., and Ku T. L. (1992) *Uranium-Series Disequilibrium: Applications to Earth, Marine, and Environmental Problems*, 2nd edn., Oxford: Clarendon Press.

Jannik, G.T., Baker, R.A., Lee, P.L., Eddy, T.P., Blount, G.C., & Whitney, G.R. (2013) *`Long-Term Assessment of Critical Radionuclides and Associated Environmental Media at the Savannah River Site – 13038`*, WM2013: Waste Management Conference: International collaboration and continuous improvement, United States.

Keith, L.H. (1991) *Environmental sampling and analysis, A practical Guide*, USA: Lewis Publisher.

Khater, A.E.M., (1997) *Radiological Study on the Environmental Behaviour of Some Radionuclides in Aquatic Ecosystem, Ph.D. thesis*, Cairo: Biophysics Dep., Faculty of science, Cairo University.

Khatun R., Saadat A. H. M., Ahasan M.M. and Aktar S. (2013) 'Assessment of Natural Radioactivity and Radiation Hazard in Soil Samples of Rajbari District of Bangladesh', *Jahangirnagar University Environmental Bulletin,* 2(2013), pp. 1 -8.

Knoll, G. F. (2010) *Radiation Detection and Measurement*, 4th edn., USA: John Wiley & Sons.

Kusdiana S. & Iskandar D. (2015) 'Concentration of Natural Radionuclides in Soil and Assessment of External Exposure to the Public in Bangka - Belitung Islands, Indonesia', *International Journal of Sustainable Energy and Environment,* 3(1), pp. 1 -11.

Lidman, F. (2005). Isotopic Disequilibrium for Assessment of Radionuclide Transport in Peat Lands : Uranium-Thorium Series Nuclides in a Core from Klarebäcksmossen, Oskarshamn, Sweden (Dissertation). Institutionen för geovetenskaper, Uppsala. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-88889

Love, A.H., Esser, B.K., Hunt, J.R. (2003) 'Reconstructing Contaminant Deposition in a San Francisco Bay Marina, California', *J. Environ. Eng. (New York),* 129(7), pp. 659 -666 [Online]. Available at: *DOI: 10.1061/(ASCE)0733-9372(2003)129:7(659)*.

Manolopoulou, M., Stoulos, S., Mironaki, D. and Papastefanou, C. (2003) 'A New Technique for The Accurate Measurement Of ^{226}Ra By Gamma Spectroscopy In Voluminous Samples', *Nuclear Instruments and Methods in Physics Research Section A Accelerators Spectrometers Detectors and Associated Equipment,* 508(3), pp. 362 -366.

Mauring A., and Gäfvert, T. (2015) 'Radon Tightness Of Different Sample Sealing Methods For Gamma Spectrometric Measurements Of 226Ra', *American Scientific Research Journal for Engineering, Technology, and Sciences,* 14(1), pp. 1 -11.

Meindinyo R.K. and Agbalagba E.O. (2012) 'Radioactivity Concentration And Heavy Metal Assessment Of Soil And Water, In And Around Imirigin Oil Field, Bayelsa State, Nigeria', *Journal of Environmental Chemistry and Ecotoxicology* , 4(2), pp. 29 -34.

Merrill Eisenbud & Thomas Gesell (1997) *Environmental radioactivity from natural, industrial and military sources*. 4th Edition. Academic Press, Inc.

Merz, S., Shozugawa, K. and Steinhauser, G. (2015) 'Analysis of Japanese Radionuclide Monitoring Data of Food Before and After the Fukushima Nuclear Accident', *Environmental Science & Technology,* 49(5), pp. 2875 -2885.

Mujahid, S. A., Rahim, A., Hussain, S., Farooq, M., (2008) 'Measurements of natural radioactivity and radon exhalation rates from different brands of cement used in Pakistan', *Radiation Protection Dosimetry,* 130(2), pp. 206 - 212.

Musthafa, M. S. (2012) 'Natural radioactivity and dose rates for soil samples around Tiruchirapalli, South India using γ-ray spectrometry', *Radiation Protection and Environment*., 35(1), pp. 43-51.

Nadal, M., Casacuberta. N., Garcia-Orellana, J., *et al*. (2010) 'Human Health Risk Assessment Of Environmental And Dietary Exposure To Natural Radionuclides In The Catalan Stretch Of The Ebro River, Spain', *Environ Monit. Assess. ,* 175(1-4), pp. 455 -468 [Online]. Available at: *doi:10.1007/s10661-010-1543-z*.

Najat, K.M. and Mohamed, S.M. (2013) 'Natural Radioactivity in Soil and Water from Likuyu Village in the Neighbourhood of Mkuju Uranium Deposit', *International Journal of Analytical Chemistry*, 2013(Article ID 501856), pp. 1 -4 [Online]. Available at: *https://doi.org/10.1155/2013/501856*.

Nasirian, M., Bahari, I. and Abdullah, P. (2008) 'Assessment of Natural Radioactivity In Water And Sediment From Amang (Tin Tailing) Processing Ponds', *The Malaysian Journal of Analytical Sciences*, 12(1), pp. 150 -159.

National Council on Radiation Protection and Measurements (NCRP) (1984) Exposure from the Uranium Series with Emphasis on Radon and Its Daughters, Report No. 77, Bethesda: NCRP.

National Council on Radiation Protection and measurements NCRP (1992) Exposure of the population in the united states and Canada from natural background radiation Report No.94. Bethesda: NCRP.

Nursyairah Arshad, Zaini Hamzah, Ab. Khalik Wood1, Ahmad Saat, (2016) "Assessment of Radionuclides (Uranium and Thorium) Atmospheric Pollution Around Manjung District, Perak Using Moss as Bio-indicator", AIP Conference Proceedings, Advancing Nuclear Science and Engineering for Sustainable Nuclear Energy Infrastructure, AIP Conf. Proc. 1704

Olise, F. S., Akinnagbe, D. M., & Olasogba, O. S. (2016) 'Radionuclides and radon levels in soil and ground water from solid minerals-hosted area, south-western Nigeria'. *Cogent Environmental Science*, 2(1), 1142344. https://doi.org/10.1080/23311843.2016.1142344

Omar, A.O. (2019) "*Measurements of Naturally Occurring Radioactive Materials in Environmental & Ore Samples using HpGe Detector*", M.Sc. thesis, Military Technical College, Egypt.

Oni,n O., Farai, I. and Awodugba, A. (2011) 'Natural Radionuclide Concentrations and Radiological Impact Assessment of River Sediments of the Coastal Areas of Nigeria', *Journal of Environmental Protection*, 2(4), pp. 418 -423 [Online]. Available at: *doi: 10.4236/jep.2011.24047*

Organo, C. and Fenton, D. (2008) *Radiological Assessment of NORM Industries in Ireland-Radiation doses to workers and members of the public*, Dublin: Radiological Protection institute of Ireland.

Organo, C., Lee, E. M., Menezes, G., & Finch, E. C. (2005). Investigation of occupational radiation exposures to NORM at an Irish peat-fired power station and potential use of peat fly ash by the construction industry. *Journal of radiological protection: official journal of the Society for Radiological Protection*, *25*(4), 461–474. https://doi.org/10.1088/0952-4746/25/4/008

Pandit G.G., Sahu S.K. and Puranik V.D. (2011) 'Natural Radionuclides From Coal fired Thermal Power Plants-Estimation Of Atmospheric Release And Inhalation Risk', *Radioprotection*, 46(6), pp. S173 -S179 [Online]. Available at: *DOI: 10.1051/radiopro/20116982s*

Pereira, W. & Kelecom, A. (2009) `Activity of natural radionuclides and their contribution to the absorbed dose in the fish cubera snapper (Lutjanus cyanopterus, Cuvier, 1828) on the Coast of Ceara, Brazil`, *Brazilian Journal of Oceanography*. 58 (special issue IICBBM). pp.25-32.

Péter Völgyesi, (2015) "*Environment geochemical and radiometric study of building materials and attic dust samples affected by industrial activity in Hungary*", Ph.D. thesis, Lithosphere Fluid Research Laboratory, Department of Petrology and Geochemistry, Eötvös Loránd University.

Porstendörfer J. (1994) `Properties and behaviour of radon and thoron and their decay products in the air`, *Journal of Aerosol Science*, 25 (1994), pp. 219 –263.

Radenkovici, M.B., Elshikh, S.M., Andric, V.B. and Miljanic, S.S. (2009) 'Radioactivity of Sand From Several Renowned Public Beaches And Assessment Of The Corresponding Environmental Risks', *Journal of Serbian Chemical Society*, 74(4), pp. 461 -470.

Rafique, M., (2014) 'Cesium-137 activity concentrations in soil and brick samples of Mirpur, Azad Kashmir; Pakistan', *International Journal of Radiation Research*, 12(1), pp. 39 - 46.

Ramasamy, V., Senthil, S., Meenakshisundaram, V., Gajendran, V., (2009) 'Measurement of Natural Radioactivity In Beach Sediments From North East Coast of Tamilnadu, India', *Research Journal of Applied Sciences, Engineering and Technology* , 1(2), pp. 54 - 58.

Rashed-Nizam, Q. M., Rahman, M. M., Kamal, M., & Chowdhury, M. I. (2015). `Assessment of radionuclides in the soil of residential areas of the Chittagong metropolitan city, Bangladesh and evaluation of associated radiological risk. *Journal of radiation research*, *56*(1), pp.22 –29. https://doi.org/10.1093/jrr/rru073

Righi S., Lucialli P. and Bruzzi L. (2005) 'Health and Environmental Impacts of A Fertilizer Plant Part I: Assessment Of Radioactive Pollution', *Journal of Environmental Radioactivity*, 82(2), pp. 167 -182.

Sahu S.K., Ajmal P.Y., Bhangare R.C., Tiwari M., Pandit G.G. (2014) 'Natural Radioactivity Assessment of A Phosphate Fertilizer Plant Area', *Journal of Radiation Research and Applied Sciences*, 7(1), pp. 123 -128.

Salama, E., EL-Fiki, S.A., Ibrahim, A., & Diab, H.M. (2015). Distribution of Radionuclides in Soil and Beach Samples of the Western Coast of Suez Gulf, Egypt. Arab Journal of Nuclear Sciences and Applications, 48(2), 63-69.

Saleh, I. H. (2012) 'Radioactivity of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs and Assessment Of Depleted Uranium In Soil Of The Musandam Peninsula, Sultanate Of Oman', *Turkish J. Eng. Env. Sci.*, 36(2012), pp. 236 – 248.

Saleh, A. S. and Yun, J.-I. (2017) "Equilibrium and Kinetics of Calcium-Uranyl-Carbonate Adsorption on Silica Nanoparticles," *Journal of Radioanalytical and Nuclear Chemistry : An International Journal Dealing with All Aspects and Applications of Nuclear Chemistry*, 314(1), pp. 93–103. doi: 10.1007/s10967-017-5395-7.

Salminen, R., Batista, M.J., Bidovec, M., Demetriades, A., De Vivo, B., De Vos, W., Duris, M., Gilucis, A., Gregorauskiene, V., Halamić, Josip *et al*. (2005) *Geochemical Atlas of Europe, Part 1, Background Information, Methodology and Maps*, Espoo: Geological Survey of Finland.

Santawamaitre, T. (2012) *'An Evaluation of the Level of Naturally Occurring Radioactive Materials in Soil samples along the Chao Phraya River Basin'* Phd thesis, Department of Physics Faculty of Engineering and Physical Sciences, University of Surrey.

Sarojini V. (2014) 'Baseline Assessment Of Dose Due To Natural Radionuclides In Soils Of Coastal Regions Of Kanyakumari District In Tamil Nadu, India', *Journal of Environmental Science, Toxicology and Food Technology,* 8(9), pp. 01 -04.

Shabaka, A.N., Ahmed, O., El-Mongy, S. and Tawfic, A. (2020) 'Analysis Of Natural Radionuclides And ^{137}Cs Using Hpge Spectrometer And Radiological Hazards Assessment For Al-Nigella Site, Egypt', *International Journal of Environmental Analytical Chemistry,* [Online]. Available at: *DOI: 10.1080/03067319.2020.1724985* ISSN: 0306-7319

Shahid, S. A., Abdelfattah, M. A, Arshad, K. R, Muhairbi; M, Al Othman, Y. R, Al Haji, A, Mansouri, M, Al Ahmed, S, Siddiqui, A, Azimullah, K. M, Sekaly A. L and Al Qubaisi, B. S. (2004). Soil Survey for the coastline of Abu Dhabi Emirate, two volumes (Volume 1: Reconnaissance Survey and Volume 2: Soil Maps). Unpublished Report of the Environment Agency - Abu Dhabi, the UAE.

Sheard, J. W., Swanson, S. M., & Godwin, R. C. (1988). Natural uranium series radionuclides in the Upland vegetation of northern Saskatchewan and adjacent Northwest Territories. Saskatoon, Saskatchewan Research Council, (SRC) Technical Report (217)

Sherif, M., Akram, S. and Shetty, A. (2009) 'Rainfall Analysis for the Northern Wadis of United Arab Emirates: A Case Study', *Journal of Hydrologic Engineering*, 14(6), pp. 535 - 544.

Shetty, P.K., Narayana, Y., Siddappa, K., (2006) 'Vertical Profiles And Enrichment Pattern Of Natural Radionuclides In Monazite Areas Of Coastal Kerala', *Journal of Environmental Radioactivity*, 86(1), pp. 132 -142.

Sroor A., Afifi, S.Y., Abdel-Haleem, A.S., Salman, A.B., Abdel-Sammad, M., (2002) 'Environmental pollutant isotope measurements and natural radioactivity assessment for

North Tushki area, south Western desert, Egypt'. *Applied Radiation and Isotopes,* 57 (3), 427–436.

Sroor, A., El-Bahi, S.M., Ahmed, F., Abdel-Haleem, A.S., (2001) 'Natural radioactivity and radon exhalation rate of soil in southern Egypt', *Applied Radiation and Isotopes*, 55(2001), pp. 873–879.

Tanner A. B., "Radon migration in the ground: a review." (1964): 161–190. In: Adams, J.A.S., Lowder, W.M. "The natural radiation environment" University of Chicago Press, Chicago.

Tanner A. B., "Radon migration in the ground: supplementary review." (1980): 5–56. In: Gesell, T.F., Lowder, W.M. "Proceedings natural radiation environment III," National Technical Information Service, Washington

Tari, M., Moussavi-Zarandi, S.A., Mohammadi, K., Zare, M.R., (2013) 'The Measurement of Gamma-Emitting Radionuclides In Beach Sand Cores Of Coastal Regions Of Ramsar, Iran Using Hpge Detectors', *Marine Pollution Bulletin,* 74(1), pp. 425-434.

Taylor J. K. and H.V. Opperman (1998); Handbook for the quality Assurance of Metrological Measurements, Lewis Publ., Chelsea.

Tesfatsion, Y. (2012) 'Studies of the transfer of radionuclides and dose rate assessments in the pasture lands located in the counties of Uppsala and Jämtland', Master´s thesis in Environmental Science'', Department of Soil and Environment, Swedish University of Agricultural Sciences.

The International Commission on Radiological Protection ICRP (1977). Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. Ann. ICRP 1 (3).

The International Commission on Radiological Protection ICRP (1995). Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients. ICRP Publication 72. Ann. ICRP 26 (1).

Thompson, M., Ellison, S. L. R. And Wood, R (2002) 'Harmonized Guidelines For Single Laboratory Validation Of Methods Of Analysis IUPAC Technical Report ', *Pure Appl. Chem.,* 74(5), pp. 835 –855.

Till, J.E & Meyer, H.R (1983) *Radiological Assessment A Textbook on Environmental Dose Analysis NUREG/CR-3332 ORNL-5968,* USA: US Nuclear Regulatory Commission.

Tykva, R & Berg, D (2004). Man-Made and Natural Radioactivity in Environmental Pollution and Radiochronology. Germany: Springer-Science+Business Media, BV.

Umar A.M., Onimisi M.Y., and Jonah S.A., (2012) 'Baseline Measurement of Natural Radioactivity in Soil, Vegetation and Water in the Industrial District of the Federal Capital Territory (FCT) Abuja, Nigeria', *British Journal of Applied Science & Technology*, 2(3), pp.266-274.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1982) *Ionizing Radiation: Sources and biological effects UNSCEAR Report 1982,* New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1988) *Sources, Effects and Risks Of Ionizing Radiation UNSCEAR Report 1988,* New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1993) *Sources and Effects of Ionizing Radiation UNSCEAR Report 1993*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1996) *Sources and Effects of Ionizing Radiation UNSCEAR Report 1996*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2000) *Sources and Effects of Ionizing Radiation UNSCEAR Report 2000*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2010) *Sources and Effects of Ionizing Radiation UNSCEAR Report 2008*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2011) *Sources and Effects of Ionizing Radiation UNSCEAR Report 2010*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2014) *Sources and Effects of Ionizing Radiation UNSCEAR Report 2013*, New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2016) *Sources, Effects and Risks Of Ionizing Radiation UNSCEAR Report 2016,* New York: United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (2015) *Developments Since The 2013 UNSCEAR Report on The Levels and Effects of Radiation Exposure Due to The Nuclear Accident Following the Great East-Japan Earthquake and Tsunami White Paper 2015*, New York: United Nations.

US. Environmental Protection Agency EPA (2002), Guidance on Choosing a Sampling Design for Environmental Data Collection for Use in Developing a Quality Assurance Project Plan, EPA QA/G-5S.

White R. E. (1981) *Introduction to The Principles and Practice of Soil Science,* USA: Wiley–Blackwell Publication.

Whittig, L.D. and Allardice, W.R. (1986) 'X-Ray Diffraction Techniques', in Klute, A (ed.) *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods.* Madison: American Society of Agronomy, pp. 331 -362.

World Health Organisation WHO (2016) Ionizing radiation, health effects and protective measures, *Available at:* https://www.who.int/topics/radiation_ionizing/en/ *(Accessed: 2nd September 2019).*

World Nuclear Association WNA (April 2020) *Naturally Occurring Radioactive Materials (NORM)*, Available at: *https://www.world-nuclear.org/information-library/safety-and-security/radiation-and-health/naturally-occurring-radioactive-materials-norm.aspx*

Yehuwdah E. Chad-Umoren and Inimbom J. Umoh (2014) 'Baseline Radionuclide Distribution Patterns in Soil and Radiation Hazard Indices for Abak, Nigeria', *Advances in Physics Theories and Applications*, 32(2014), pp. 69 -79.

Zare, M.R., Mostajaboddavati, M., Kamali, M., Abdi, M.R., Mortazavi, M.S., (2012) '^{235}U, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs Activity Concentrations In Marine Sediments Along The Northern Coast Of Oman Sea Using High-Resolution Gamma-Ray Spectrometry', *Marine Pollution Bulletin* , 64(9), pp. 1956–1961.

Appendixes

Appendix A: Mechanical (Particle Size) Analysis of the Soil samples in the Three Regions

Sample Code	Soil Separates (mm) %					< 0.063	Textural Class
	2 – 1	1 - 0.5	0.5 - 0.25	0.25 - 0.125	0.125 - 0.063		
S2	8.80	30.10	26.40	27.35	4.10	3.25	Sand
S5	2.10	7.33	60.90	16.80	11.70	1.17	Sand
S6	7.50	18.25	29.35	30.40	12.00	2.50	Sand
S7	11.78	19.75	26.75	40.22	0.75	0.75	Sand
S9	3.55	23.77	30.62	34.94	5.31	1.81	Sand
S10	6.98	10.90	10.92	41.98	25.82	3.40	Sand
S17	0.50	5.90	39.30	41.99	10.75	1.56	Sand
S18	2.00	9.80	13.90	43.10	26.95	4.25	Sand
S19	3.00	8.40	26.50	44.50	14.50	3.10	Sand
S21	5.32	11.70	33.44	36.32	10.60	2.62	Sand
S23	1.66	20.20	38.40	35.67	3.30	0.77	Sand
S25	3.95	8.45	26.55	36.60	21.05	3.40	Sand
S26	0.04	0.47	47.38	50.78	1.21	0.12	Sand
S28	0.10	1.75	44.62	51.83	1.62	0.08	Sand
S29	3.20	14.47	15.47	57.05	9.56	0.25	Sand
S30	3.00	8.90	33.10	39.80	13.00	2.20	Sand
S31	1.87	9.76	38.76	36.97	10.68	1.96	Sand
S32	1.55	7.00	25.65	47.45	17.10	1.25	Sand
S33	5.70	13.35	24.72	32.83	21.10	2.30	Sand
S34	0.15	6.40	60.70	31.50	0.55	0.70	Sand
S35	0.00	0.43	45.77	52.26	1.50	0.04	Sand
S36	0.53	13.92	80.15	3.05	1.75	0.60	Sand
S37	0.16	4.11	49.70	40.10	5.50	0.43	Sand
S41	0.30	19.24	71.99	8.25	0.15	0.07	Sand
S42	0.65	9.00	59.17	30.35	0.63	0.20	Sand
S45	0.03	1.20	27.00	70.10	1.65	0.02	Sand
S46	0.60	18.29	50.40	27.60	2.36	0.75	Sand
S47	0.34	1.69	29.15	66.80	1.80	0.22	Sand
S48	4.60	20.25	43.40	28.70	2.20	0.85	Sand
S50	0.04	1.59	41.10	55.20	2.00	0.07	Sand
S51	3.00	10.00	38.10	48.08	0.67	0.15	Sand
S53	2.52	49.80	33.64	8.80	4.87	0.37	Sand
S54	1.95	17.50	51.25	26.91	2.02	0.37	Sand
S56	10.35	28.60	24.71	33.77	2.42	0.15	Sand
S58	2.68	19.66	49.59	22.49	4.18	1.40	Sand
S59	3.25	14.50	19.10	50.50	10.85	1.80	Sand
S60	0.60	8.85	47.50	42.43	0.55	0.07	Sand
S62	6.00	17.30	39.00	30.20	5.50	2.00	Sand
S64	2.90	18.95	45.52	26.35	4.90	1.38	Sand
S66	10.82	20.95	31.77	23.80	8.22	4.44	Sand
S68	15.10	46.00	32.15	6.45	0.20	0.10	Sand
S70	9.20	26.50	37.21	26.35	0.30	0.44	Sand
S73	11.25	16.80	25.70	38.35	6.25	1.65	Sand
S70	5.00	16.20	52.70	20.50	3.50	2.10	Sand

Appendix B: Chemical analysis results of the soil samples in the three regions

Sample Code	pH (1:2.5)	EC dSm^{-1}	$CaCO_3$ %	Sample Code	pH (1:2.5)	EC dSm^{-1}	$CaCO_3$ %
S2	7.92	8.05	64.44	S41	7.72	2.21	79.09
S4	8.3	46.8	17.24	S42	8.17	1.48	93.18
S6	8	40.2	32.33	S45	8.36	0.87	90
S5	8.14	0.95	42.22	S46	8.24	1.2	98.64
S6	7.84	9.7	9.09	S47	8.38	0.23	97.73
S7	7.77	4.04	75.91	S48	8.26	0.52	81.82
S9	8.06	2.4	53.33	S50	8.45	0.33	86.36
S10	8.06	10.89	68.97	S51	8.7	1.24	82.73
S17	8.04	11.93	24.44	S53	8.13	2.06	97.73
S18	7.75	6.64	66.67	S54	8.2	0.45	88.64
S19	7.74	22.1	53.33	S56	7.98	0.85	77.27
S21	8.11	21.2	75.56	S58	8.18	0.75	65
S23	8.14	3.79	81.78	S59	8.21	0.46	70.91
S25	7.85	21.2	61.36	S60	8.38	0.29	78.18
S26	8.47	2.46	82.22	S62	8.21	0.55	45.45
S28	8.1	3.13	90	S64	8.18	1.47	15.91
S29	8.21	4.04	76.44	S66	7.66	7	56.82
S30	7.96	4.56	79.55	S68	8.25	2.79	84.09
S31	8.08	2.95	80	S70	8.04	4.95	88.64
S32	8.22	2.6	75.91	S73	8.01	1.95	43.18
S33	7.85	7.5	71.11	S70	7.73	36.1	33.62
S34	8.011	1.76	86.67	S77	8.09	20.6	88.64
S35	8.33	2.68	75	S78	7.71	16.89	68.1
S36	8.07	4.48	84.09	S80	8.04	57.4	47.41
S37	8.19	1.3	93.18	S82	8.05	38	28.02

Appendix C: Mechanical analysis of the analysed shore sediment samples

Sample Code	Soil Separates (mm) %					< 0.063	Textural Class
	2 – 1	1 - 0.5	0.5 - 0.25	0.25 - 0.125	0.125 - 0.063		
SS1	0.35	0.70	22.49	69.93	6.40	0.13	Sand
SS2	2.60	12.28	65.85	17.12	1.00	1.15	Sand
SS3	7.00	26.50	62.00	4.47	0.02	0.01	Sand
SS4	0.25	0.50	5.75	90.95	2.51	0.04	Sand
SS5	2.43	24.49	60.95	9.63	2.41	0.09	Sand
SS6	5.50	8.30	26.76	46.26	13.10	0.08	Sand
SS7	17.20	16.66	48.90	16.74	0.40	0.10	Sand
SS9	3.91	7.66	11.21	61.12	15.85	0.25	Sand
SS11	31.50	37.40	15.74	11.46	3.88	0.02	Sand
SS18	3.00	4.60	9.30	63.00	18.50	1.60	Sand
SS19	1.50	4.70	23.60	33.10	35.10	2.00	Sand
SS21	0.61	1.63	37.85	55.75	3.96	0.20	Sand
SS25	2.00	3.00	11.50	46.55	33.45	3.50	Sand
SS26	9.50	31.20	40.09	18.00	1.20	0.01	Sand
SS28	10.86	33.38	42.67	10.65	2.41	0.03	Sand
SS30	2.40	12.07	35.47	40.25	9.66	0.15	Sand
SS32	2.00	27.45	50.55	14.17	5.76	0.07	Sand
SS33	10.50	32.50	41.65	10.50	4.50	0.35	Sand
SS35	2.72	17.04	39.85	38.75	1.63	0.01	Sand
SS36	0.25	7.90	60.59	29.35	1.90	0.01	Sand
SS37	6.00	43.44	49.11	1.00	0.43	0.02	Sand
SS41	1.15	13.27	36.03	44.65	4.83	0.07	Sand
SS42	74.22	24.55	0.80	0.40	0.02	0.01	Sand
SS45	15.15	59.34	22.30	3.00	0.20	0.01	Sand
SS46	8.50	41.01	38.30	11.53	0.65	0.01	Sand
SS47	4.00	21.00	43.00	31.59	0.40	0.01	Sand
SS48	0.88	18.60	66.41	14.05	0.05	0.01	Sand
SS50	33.30	42.75	21.00	2.50	0.44	0.01	Sand
SS51	4.00	8.60	11.20	46.16	30.00	0.04	Sand
SS53	31.18	50.47	5.45	7.80	5.05	0.05	Sand
SS54	4.20	19.85	61.44	14.10	0.38	0.03	Sand
SS56	0.90	5.27	25.15	64.50	4.17	0.01	Sand
SS58	10.10	25.85	16.30	38.60	7.25	1.90	Sand
SS59	17.00	33.10	26.39	22.00	1.50	0.01	Sand
SS60	18.00	19.60	19.30	37.10	5.97	0.03	Sand
SS62	1.20	15.80	54.08	26.00	2.90	0.02	Sand
SS64	0.25	2.85	18.75	61.35	16.75	0.05	Sand
SS66	42.00	29.25	17.40	9.30	2.00	0.05	Sand
SS68	33.60	48.25	14.42	3.30	0.35	0.08	Sand
SS70	31.91	50.10	14.85	3.08	0.05	0.01	Sand
SS73	40.00	36.00	8.00	12.65	3.20	0.15	Sand
SS74	22.50	24.70	36.80	15.00	0.90	0.10	Sand
SS77	6.00	28.00	55.38	10.20	0.40	0.02	Sand
SS78	8.00	65.20	25.38	1.10	0.30	0.02	Sand
SS80	34.20	58.29	6.54	0.80	0.16	0.01	Sand

Appendix D: Chemical analysis results of the analysed shore sediment samples

Sample Code	pH (1:2.5)	EC dSm^{-1}	$CaCO_3$ %	Sample Code	pH (1:2.5)	EC dSm^{-1}	$CaCO_3$ %
SS1	7.58	7.46	65.91	SS46	8.26	2.98	90.91
SS2	8.16	2.75	11.11	SS47	8.07	3.42	98.64
SS4	7.78	10.03	69.55	SS48	8.2	1.96	93.18
SS5	8.3	3.35	60.89	SS50	8.18	3.33	90.91
SS6	8.12	5.38	28.89	SS51	8.2	3.7	70.45
SS7	7.97	7.17	72.89	SS53	8.29	3.4	87.73
SS9	8.06	9.64	60	SS54	8.24	2.9	84.09
SS11	8.33	3.17	74.67	SS56	8.34	2.87	69.55
SS18	7.8	11.46	63.64	SS58	8.08	4.19	65.45
SS19	7.91	20	46.67	SS59	7.93	2.73	95.45
SS21	7.74	10.94	73.33	SS60	8.36	2.48	70.45
SS25	8	6.99	62.27	SS62	8.01	4.11	27.27
SS26	8.21	3.66	97.78	SS64	8.15	4.95	18.18
SS28	8.17	4.73	93.33	SS66	8.37	2.03	63.64
SS30	8.14	3.36	72.89	SS68	8.19	3.2	86.36
SS32	8.2	3.02	91.11	SS70	8.12	3.76	95.45
SS33	8.15	4.51	97.78	SS73	8.29	3.35	81.82
SS35	8.38	3.39	90.91	SS74	8.36	2.15	11.36
SS36	8.19	4.29	86.67	SS77	8.34	3.36	95.45
SS37	8.24	2.6	90.91	SS78	8.37	2.51	92.27
SS41	7.98	5.13	86.36	SS80	8.32	2.17	93.33
SS42	8.15	4.22	93.18	SS82	8.22	4.03	32.44
SS45	8.21	2.96	90				

Appendix E: A comparison of Chemical analysis results for both shore sediment and soil samples

Chemical analysis of some shore sediment samples				**Chemical analysis of some soil samples**			
Sample Code	**pH (1:2.5)**	**EC dSm^{-1}**	**$CaCO_3$ %**	**Sample Code**	**pH (1:2.5)**	**EC dSm^{-1}**	**$CaCO_3$ %**
SS2	8.16	2.75	11.11	S2	7.92	8.05	64.44
SS5	8.3	3.35	60.89	S5	8.14	0.95	42.22
SS6	8.12	5.38	28.89	S6	7.84	9.7	9.09
SS21	7.74	10.94	73.33	S21	8.11	21.2	75.56
SS25	8	6.99	62.27	S25	7.85	21.2	61.36
SS30	8.14	3.36	72.89	S30	7.96	4.56	79.55
SS36	8.19	4.29	86.67	S36	8.07	4.48	84.09
SS46	8.26	2.98	90.91	S46	8.24	1.2	98.64
SS48	8.2	1.96	93.18	S48	8.26	0.52	81.82
SS50	8.18	3.33	90.91	S50	8.45	0.33	86.36
SS51	8.2	3.7	70.45	S51	8.7	1.24	82.73
SS53	8.29	3.4	87.73	S53	8.13	2.06	97.73
SS54	8.24	2.9	84.09	S54	8.2	0.45	88.64
SS56	8.34	2.87	69.55	S56	7.98	0.85	77.27
SS66	8.37	2.03	63.64	S66	7.66	7	56.82
SS70	8.12	3.76	95.45	S70	8.04	4.95	88.64
SS74	8.36	2.15	11.36	S74	7.73	36.1	33.62
SS77	8.34	3.36	95.45	S77	8.09	20.6	88.64
SS78	8.37	2.51	92.27	S78	7.71	16.89	68.1
SS80	8.32	2.17	93.33	S80	8.04	57.4	47.41
SS82	8.22	4.03	32.44	S82	8.05	38	28.02