CHAPTER ONE

INTERODUCTION

After the discovery of radioactivity in 1896 by A. H. Becquerel, There for numerous studies have been reported on radioactivity and radiation, Radionuclides are found all around us in our environment, in the atmosphere, beneath the earth and even within us. Sources of radionuclides include those that exist before the creation of the earth (primordial sources), those that result from cosmic ray interactions (cosmogenic sources) and those that result from human activities, (Ajibode.M. O et at., 2013).

Natural Envronmental radioactivity is composed of the cosmogenic and terrestrial radionuclides. (UNSCEAR, 2008) reported that estimation of 80% of doses contribution in the environment are derived from the natural radionuclides while the remaining 20% is from cosmic ray and processes ,Cosmogenic radionuclides, such as ^{3}H,^{7}B, ^{14}C and ^{22}Na, are produced by the interaction of cosmic-ray particles in the earth's atmosphere. Terrestrial radionuclides (^{40}K, ^{238}U and ^{232}Th series) are formed by the process of nucleosynthesis in stars. Only those radionuclides with half-lives comparable to the age of the earth, and their decay products, can still be found today on earth, Terrestrial gamma radiation is one of the main constituents of background radiation and is strongly dependent on the composition of the soil and the rocks and the radionuclides contained within them claims, the dose rate of terrestrial gamma radiation is mainly attributed to differences in their geological nature of the place ,Gamma radiation from these radionuclides represents the main external source of irradiation of the human body (Michalis Tzortzis et at., 2003, A. S. ALaamer, 2008).

There are two prominent sources of external gamma-rays which are derived mainly from naturally occurring radioactive materials (NORM) which are present in soils have been shown to contribute at least 85% of the natural background radiation. This implies that (NORM) have been the largest contributors to the collective dose received by the world population. A part from natural sources, many contribute to radiation level in the environment. Oil and gas production and processing operations sometimes cause NORM to accumulate at elevated concentrations in by-product waste streams. The improper use and disposal of NORM can also result in significant contamination of the environment (Alatise et al., 2008).

The exposure to ionizing radiations from natural sources occurs because of the naturally occurring radioactive materials in the soil and rocks, cosmic rays entering the earth's atmosphere from outer space and the internal exposure from radioactive elements through food, water and

air. Natural radioactivity is widespread in the earthenvironment and it exists in various geological formations such as earth crust, rocks, soils, plants, water and air (Surinder Singha et at., 2005, Avwiri. G. O et at., 2012). So the Knowledge of the distribution pattern of the both anthropogenic and natural radionuclides in soil plays an important role in radiation protection and measurement.

Most of the radioactivity in the terrestrial environment whether it is naturalor man-made, is bound to the components of the soil. Transportation of this Radioactivity from soil is possible to vegetation via dust deposition or root uptake, water sources by flood wash-down, and forward to humans through inhalation, breathing and soil ingestion. Therefore, all pathways of exposure that originate from soil are potentially important for the purpose of radiation risk assessment (AShousha.H.A et at., 2009).

For health and environmental safety purposes there is need to measure and evaluate the level of radioactivity in the environment regularly and Estimation of the radiation dose distribution is vital in assessing the health risk to a population and serves as a reference for documenting changes in environmental radioactivity due to anthropogenic activities

Assess and monitoring radioactivety are therefore of primary importance for humans, organisms and for environmental protection, but rapid and accurate methods for the assay of radioactivity is essential and initiate radiation map of the countrys. (S. Harb et at., 2014, Mahmoud Ibrahim et at., 2014).

This study is a part of national programmer for monitoring environmental radioactivity contributing towards producing a radiation map for Sudan which started in 1985's , the broad objective of producing radiation map for Sudan to be used as a reference in the case of any radiation emergency of potential environmental impacts, Since are many of studies on environmental radioactivity monitoring and evaluations of public exposure have been conducted many region in Sudan mainly ,the study was extended to include the western part of the country, and Attention had been focused on determining the levels of radioactivity .It is helped that the information obtained will initiate a radiation map of the country.

1.2 General statement of the problem:

Since its existence in the environment that we live in, every living creature is exposed to ionizing radiation. This radiation is a part of the earth and comes from cosmos and affects all the goods, food and even the air that we breathe and makes them partly radioactive. So, human beings are

exposed to natural background radiation every day from the ground, building materials, air, food, the universe, and even elements in their own bodies. It is because of some reasons that human and its environment are affected by radioactivity, such as, natural radionuclides which are present in soil and the atmosphere, nuclear weapon testing, radioactive wastes and reactor accidents (A. Kurnaz et at.,2007), radionuclides which at high doses and high dose rates, have serious long term effects on flora and fauna, including cancer. There is however, considerable controversy regarding the health effects of low-level radiation at or below typical natural background levels. Exposure of the population occurs through three main pathways: inhalation of airborne material, external irradiation from material deposited on the ground, and ingestion of contaminated foodstuff. Doses from external radiation and ingestion will dominate the overall dose. In areas of low deposition, all three pathways may be of similar importance. In the State of Kordfan, Sudan, the presence of abnormal radioactivity has been investigated.Sources of radiation include, besides industrial materials: staple food; vegetation products used for private medical procedures; consumption of agricultural products; water sources; and also the soil and rock which has been used as the building materials. Geographic structure of Kordofan (south, west and Nuba Mountains) as well as rocks that are rich in phosphate, granite and salt contains radionuclides like ^{238}U, ^{232}Th and ^{40}K, when rocks are disintegrated through natural processes; radionuclides are carried to soil by rain and flows. The irradiation of the human body is mainly by gamma radiation from these radionuclides. Only a few studies have been performed in this field, therefore the measurement and estimation of the dose is crucial.

1.3 General Objective of the study:

To assess the radiological environmental pollution into the environment of Kordofan State, Sudan and investigate the possible radiological risks due to dwellings made by materials of the area used as residence by the general public in the area.

1.4 Specific Objectives:

a- To assess the natural radioactivity levels in soil, vegetation, staple food and levels of artificial radionuclide’s (if exist).

b- To determine the activity concentrations of radionuclide's in different agricultural crops grown in those areas.

c- To systematically measure the terrestrial gamma radiation and determine its contribution to the annual effective dose equivalent to the population at that areas.

d- To provide necessary information of human health risks associated with terrestrial radioactivity and its effects on plant materials.

e- Establish base-line data on the gamma background radiation levels in different areas of Kordofan state (construct maps, tables,.. etc). This study compiles information from various sources to help clarify the facts, what we know about its health effects, its levels in Sudan and how it can be regulated from the experiments of research (such as an explanation radioactivity concentrations)

1.5 Thesis layout:

This research project aims to monitoring of environmental radioactivity in South and north kordofanstate, There are many principles, methods and techniques used to determine the amount of radioactivity in the environment and assessment of Doses. One of the widely used techniques is gamma-ray spectrometry which is common to all low-level radio analysis and can be applicable to other environment radioactivity. The measurements have been carried out by using high resolution gamma spectroscopy using NaI (Tl) detector with specially designed shield in a low background configuration, the results of the measured activity from the samples collected in the Kordofan State have been analyzed.

A gamma ray spectrometry is an instrument that provides information on both the energy and intensity of radiation that is emitted from a source of gamma-rays, technique can also identify various radionuclides containing in a sample.

The following **Chapter one:** is Introduction and The objectives of the study, **Chapter Two**: deals with the basic concepts of the introduction of radioactivity in the environmental media such as soil ,rocks , vegetation and staple food together with an explanation of the condition of Environmental radioactivity sources of radioactivity also are focused and Previous Studies, on in **Chapter three :** Radioactivity measurement techniques of gamma emitting radionuclide's in different environmental media and data analysis techniques including sample collection and preparation are outlined, **Chapter four**:represents the results of this current study together with the discussion of the obtained results. The **final chapter:** Conclusions of the study along with future recommendations has been depicted and provides a conclusion of this study.

CHAPTER TWO

LITETATURE REIEW

2. 1 Introduction

Radioactivity is defined as the spontaneous break down of a nucleus. The unstable, or radioactive, ones decompose by emitting alpha (α), beta (β), and gamma (γ) radiations. The biological effects related to passage of these radiations through the cells are due to changes in their chemistry caused by ionization, excitation, dissociation, and atomic displacement (Buccianti et al., 2009). Human beings are exposed to background radiation that stems both from natural and man-made sources. Therefore, knowledge of radionuclide distribution and radiation levels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and cosmogenic sources. The planet Earth is a radioactive planet and natural radiations are present in every human environment; Earth's material, water, air, foods, and even human body contains naturally occurring radioactive materials. Natural background radiation, which is equivalent to 2.4mSv per person, makes up approximately 80% of the total radiation dose a person is exposed in a year (Taskin et al., 2009, Hasan M. Khan, et al. 2011).

Natural radioactivity has played an indispensable role in the development of earth sciences (S.Labidi et at., 2010), usually the natural radionuclide's are very low activity concentrations. The primordial radionuclides ^{238}U and ^{232}Th exist in soil, in varying concentrations. These can be attributed to the nature of the parent rock during soil genesis. Studying transfer of natural radionuclides, like ^{238}U and ^{232}Th along with their daughter products through the biosphere is important because their ubiquitous presence and persistence in the environment. Soil–vegetables are recognized as one of the major pathways for the transfer of radionuclides to human beings Transmission of uranium and thorium along with nutrients through the absorption of minerals, and accumulate in various parts or even up to the edible parts (MurtadhaSh et al., 2013)

The natural or artificial radioactive nuclides that are present in the environment are main sources of radiation exposure for human beings and constitute the background radiation level. Evaluation of the distribution of these radionuclides is very necessary for assessing the effects of radiation exposure. The terrestrial component of the background is due to various radioactive nuclides that are present in air, soil, water and building materials whose abundances vary significantly depending on the geological and geographical features of a region. The cosmic component, on the other hand, originates from outer space as cosmic rays whose contribution to the background

changes mainly with elevation and latitude. In addition to the natural sources, the level of background radiation in a region is considerably affected from man-made sources such as those from nuclear activities and accidents (UNSCEAR, 2000). Therefore, many researchers throughout the world are continuously interested in measurements of natural radioactivity in air, soil and drinking water samples. (A.Kurnaz et at., 2007).

The distribution of natural and artificial radionuclides in environmental settings and the contributions of these radionuclides to the radiation dose to which people are exposed should be defined separately (G. Akkaya et at., 2012),Since the doses from tese pathways are strongly related to the amount of radionuclides present, an important objective from the point of view of the radio ecological protection of the population is the accurate evaluation of the amounts received in dietary intake (D. G. Marbaniang, 2011).

2.2 Environmental radioactivity:

Ionizing radiations enter into our lives in a variety of ways. Natural sources of radioactivity include cosmic rays, gamma rays from the Earth, radon decay products in the air, and various radionuclides in edibles and potables (Abdul jabbar, 2010).

Human beings are exposed to ionizing radiation from natural sources throughout their lifetime. Therefore, knowledge of radionuclide distribution and radiationlevels in the environment is important for assessing the effects of radiation exposure due to both terrestrial and cosmogenic sources. The planet Earth is a radioactive planet and natural radiations are present in every human environment; Earth's material, water, air, foods, and even human body contains naturally occurring radioactive material(IAEA,3013) Radionuclides present in the environment are normally found in low concentration. These may be naturally occurring (e.g. uranium-238, thorium-232, and their daughter products and potassium-40 or those produced by cosmic rays interaction in the biosphere) or man- made sources (e.g. originating from nuclear fallouts or emanating from nuclear facilities) (Hasan M. Khan, et al. 2011)

Naturally Occurring Radioactive Materials NORM has sources of natural radiation and radioactivity that are classified as extraterrestrial and terrestrial sources. In term of population radiation dose, the sources of natural radiation are the most significant and the main contributor to the population collective doses (UNSCEAR, 1988), Natural radiation sources are classified into three categories; cosmic ray, cosmogenic radionuclides and primordial (terrestrial) radionuclides.

Primordial radionuclides are long-lived species, which have been present on earth since its formation about $4.5x10^9$ years ago. They are classified into:

(i) Series radionuclides; groups of radionuclides that are headed by parent radionuclides that decay in sequence to other radionuclides with different half-lives and decay modes, and finally end as stable isotopes (NCRP,1992). There are three natural series headed by uranium-238, uranium-235 and thorium-232, the main members of which are shown in figures 2-1.

(ii) Non-series radionuclides; they decay directly to stable nuclide. The most important radionuclides are the isotopes of potassium-40, vanadium-50, rubidium-87, cadmium-113 and indium-115. In term of population dose, the most significant radionuclides are potassium-40 and rubidium-87

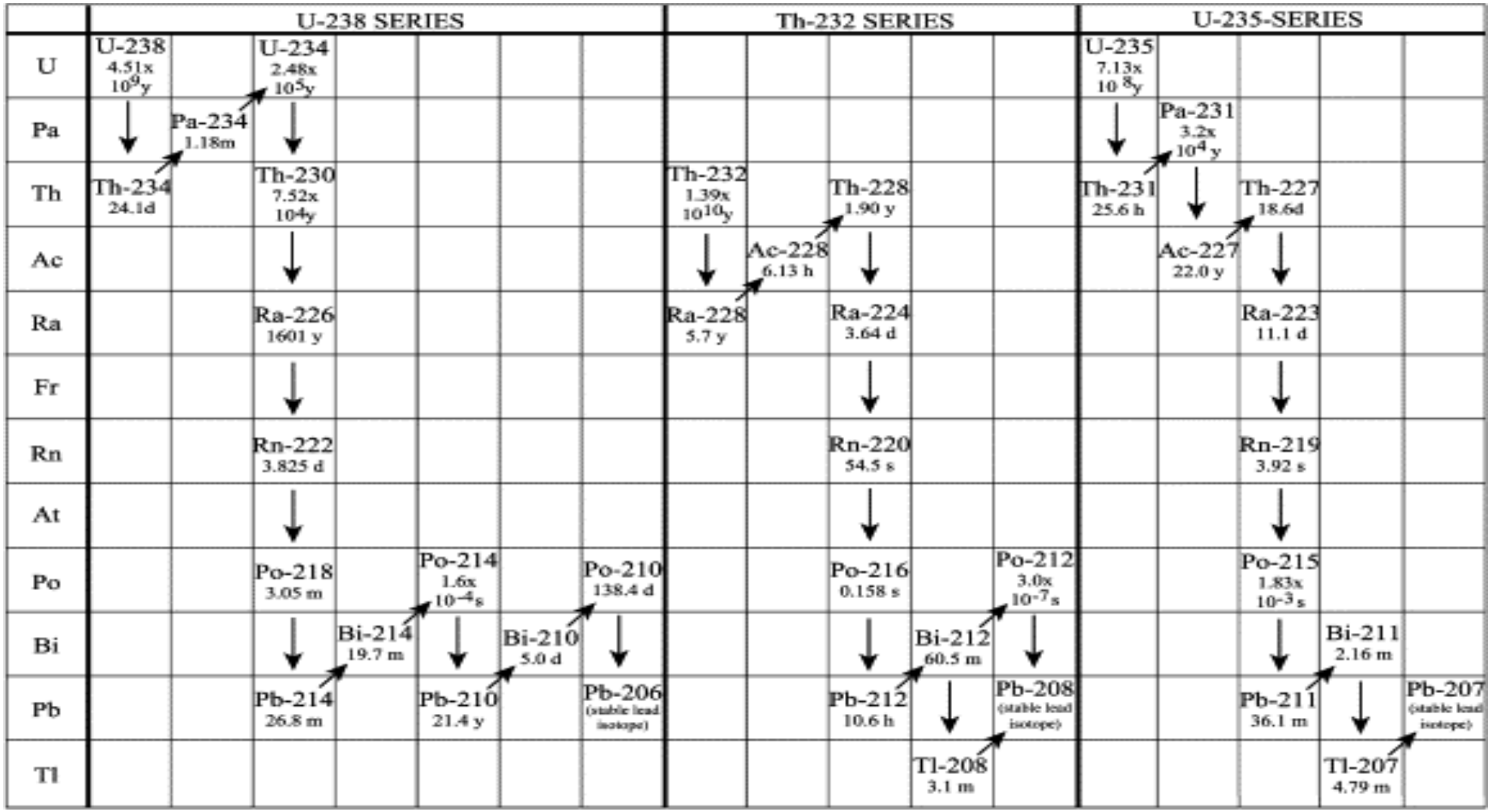


Figure 2.1: The uranium (^{238}U), thorium (^{232}Th), and actinium (^{235}U) decay series.

2.2.1 Radioactivity level in Rocks:

Radioactivity of rocks is usually caused by one of three natural sources of gamma-radiation: potassium, uranium and thorium. Each of those elements in natural conditions contains a fraction of radionuclide that can be detected in either direct or indirect way (IAEA, 2003).

Radionuclides are present in rocks in varying amounts, and they are easily mobilized into the environment. Radioactivity in soil results from the rock from which they were derived. The distributions of naturally occurring radionuclides depend on the distribution of rocks from which they originate and the processes which result to their removal from the soil and migrate them.

Therefore, the natural environmental radioactivity mainly depends on geological and geophysical conditions (E.O. Joshua et at., 2009), According to the (UNSCEAR 2000) report, higher radiation levels are associated with igneous rocks such as granite and the levels are lower in sedimentary rocks. Also phosphate rocks are known to contain relatively high content of radionuclides. There are exceptions, however, as some shales and phosphate rocks have relatively high content of radionuclides, are widely used as building materials (Michalis .Tzortzis et al., 2003). It is therefore important to measure the concentration of radionuclides in rocks that are used and those that have the potential of being used as building materials for assessing the radiological risks to human health.

Extra-terrestrial cosmic radiation in the soil and rock give us an average dose of up to 60 μ rads y^{-1} (UNSCEAR, 1982), the activity levels in soils are related to the types of rocks from which the soils originate.

The radionuclides existing in phosphate rocks can enter the human environment through several ways such as fertilization of agricultural lands, usage of phosphogypsum in agriculture and building materials. Large deposits of rock phosphate, and other phosphorous compounds, are found in many geographical localities. These deposits are of great economic value for the manufacture and agricultural fertilizers (superphosphates) (Bolca et al., 2007).

Table (1.2): Typical activity concentration of ^{40}K, ^{238U} and ^{232}Th in common rocks and estimated absorbed dose in air 1 m above the surface (UNSCEAR, 1977)

Type of rock	Typical activity Type of rock concentration (pCi g^{-1})			Absorbed dose rate in air (μ rad h^{-1})
	^{40}K	**^{238}U**	**^{232}Th**	
Igneous				
Acidic(e.g. granite)	27	1.6	2.2	12
Intermediate(e.g.diorite)	19	0.62	0.88	6.2
Mafic(e.g.basalt)	6.5	0.31	0.30	2.3
Ultrabasic (e.g.durite)	4.0	0.01	0.66	-
Sedimentary				
Limestone	2.4	0.75	0.19	2.0
Carbonate	-	0.75	0.21	1.7
Sandstone	10	0.5	0.3	3.2
Shale	19	1.2	1.2	7.9

2.2.2 Radioactivty level in soil:

Natural radioactivity in soil constitute one of the most component of the background radiation exposure to population. Human beings always exposure to ionizing radiation owing to primordial radionuclides such as ^{238}U decay series and ^{232}Th series and ^{40}K w that are found in the earth's crust, and to cosmic ray second aries, always each of us is exposed to naturally occurring quantities of radiation Sources of ionizing radiation found in soil result from the rock from which the soil is derived. Levels of ionizing radiation will vary as a result of diminution by leaching of water, dilution by increased porosity, and by augmentation from water and organic matter by sorption and precipitation of radionuclides (Einas, 2012). Average activityconcentrations of ^{40}K, ^{238}U and ^{232}Th in

various types of soil and estimated absorbed dose in air 1 m above the surface is shown in Table (2.2). It should be noted, however, that the main factor influencing the concentration of the natural radionuclides in soil is not the soil forming process but the corresponding concentration in the soil forming rocks (UNSCEAR, 1977).

Table (2.2): Average activity concentrations of ^{40}K, ^{238}U and ^{232}Th in various types of soil and estimated absorbed dose in air 1 m above the surface

Type of Soil	Average Activity Concentration($_P$Ci g^{-1})			Absorbed dose rate in air (μrad h^{-1})
	^{40}K	^{238}U	^{232}Th	
Serozem	18	0.85	1.3	7.4
Gray-brown	19	0.75	1.1	6.9
Chestnut	15	0.72	1.0	6.0
Chernozem	11	0.58	0.97	5.1
Gray forest	10	0.48	0.72	4.1
Sodpozolic	8.1	0.41	0.60	3.4
Podzlic	4.0	0.24	0.33	1.8
Boggle	2.4	0.17	0.17	1.1
World average	10	0.7	0.7	4.6
Typical range	3-20	0.3-1.4	0.2-1.3	1.4-9

2.2.3 Radioactivity levels in staple food and vegetation

Food can be contaminated with a wide range of pollutants including radioactivity, ingestion of foodstuffs constitutes an important pathway by which can be transferred to humans. There are many human activities which can enhance the level of naturally occurring radioactivity levels in the environment. As is commonly known a large contribution to the radiation dose received by humans comes from natural occurring uranium series radionuclides accumulated in the body.

Invstegation of natural radioactive isotopes present in foodstuffs and assess the dose are extremely important for controlling radiation levels to which mankind is direct or indirectly exposed. Another

important fact is that, importation of contaminated food from any region that suffered a nuclear accident can be indirectly affect people health around the world (F. L. Melquiades et al., 2004).

Consumption of food is usually the most important route by which natural radionuclides can enter the human body (I. Louw et at., 2001), Ingestion of radionuclides through food intake accounts for a substantial part of average radiation doses to various organs of the body and also represents one of the important pathways for long term health considerations. The status of the soil on which food crops are grown will determine, to a significant extent, the quality of foodstuffs produced. (N.N. Jibiri et at., 2007).

The naturally occurring radionuclides in food come mainly from natural isotopes of potassium, uranium and thorium and their daughter products. The majority of radionuclides in the environment are present as daughter products of ^{232}Th and ^{238}U, distributed by natural geological and geochemical processes, in addition to the unrelated naturally occurring ^{14}C and ^{40}K. There are many human activities which can enhance the level of naturally occurring radioactivity levels in the environment. (N .A .Mlwilo et al., 2007)

Radionuclides together with some other heavy metals are the primary toxic pollutants from the manufacture of phosphate fertilizer. Artificial fertilizing has steadily replaced the natural fertilizing in agriculture; therefore, fruits and vegetables may contain radionuclides found in phosphate fertilizers. This fact is of serious concern, because the daily intake of radionuclides with food may be considered as chronic ingestion. An investigation of the radionuclides pathway from fertilizers to plants and to humans is, therefore, very important from the viewpoint of radiological protection within the general population (Ekdal et al., 2006).

Plants organisms assimilate and deposit in their-various natural radioactive isotopes present in the soil irrespective of biological necessity. Radium enters the above-ground plant organs show no tendency to form chemical compounds of low mobility in plant tissues. Under normal environmental conditions about 90% of ^{226}R enters the human body through food. Ingestion is therefore the most important mode of exposure to be considered when assessing the dose to man. To support that work, the magnitude of soil/plant transport of naturally occurring radionuclides such as ^{226}R has to be evaluated in different regions of the world. This is necessary both for dose assessment and for predictive modeling along the terrestrial food chain (Sam and Eriksson, 1995).

In Sudan the most important kind of food are grains and roots .The maize constitutes a large percentage of the total diet, while Tomato, Okra and the leafy vegetables like Portulaca and (molokhia) come at the second level in combination with (maize) sorghum bread (ksra).

2. 3 Previous Studies

Monitoring environmental radioactivity contributing toward producing a radiation map for Sudan which started in 1985s, the broad objective of producing radiation map for Sudan to be used as a reference in the case of any radiation emergency of potential environmental impacts. Since various studies concerning on environmental radioactivity monitoring and evaluations of public exposure have been conducted in many regions in Sudan, mainly the south of the central part of Sudan was surveyed by (Magdi. Hasan. Saad ,2013) have been evaluate and describe Natural Radioactivity in Different Regions in Sudan. The analysis indicates that the concentration of radioactive elements is high at Mountains except in the Middle of the Sudan. The radiation dose rates in air are at the normal level except at Nubian areas (south of the central Sudan).The dose rate in air in northern and central regions of Sudan is in arranged which is recommended by IAEA and WHO. At east and south of the Sudan are observed high radioactivity and radiation background.

At Wastren part of sudan , (Sam *et al.*,1997) calculations of the external exposure due to gamma radiation from the ground have been made from the results of the measurements of radionuclide activity concentrations in the soil at various locations , have been reported The average exposure was found to be 45 $nGyh^{-1}$, corresponding to the annual dose equivalent of 278 μSvy^{-1}.With the exception of the Arkuri and Dumper areas in the western part of the country, the calculated exposure falls within the global wide range of outdoor radiation exposure given in the UNSCEAR publications. The nationwide average concentrations of ^{226}Ra, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs determined were 31.62, 20.11, 19.10, 280.29 and 4.12 $Bqkg^{-1}$, respectively. This shows that there is little contamination due to fallout radioactivity at survey sites.

In Centeral Sudan, (Sam et *al*., 2003), in uranium mineralization areas at Jebel Uro, Jebel Kurun and Jebel Mun in Western Sudan, absorbed dose rate received from natural external irradiation was evaluated from the measured activity concentrations of ^{238}U, ^{232}Th and ^{40}K in rock samples. The analyses were performed using alpha-spectrometry and high resolution gamma-ray spectrometry. A great spatial variability was observed in activity concentration of the primordial radionuclides indicating complexity in geological features. Compared Jebel Mun, Uro and Kurun deposits exhibit very high U: Th mass ratio, the feature that characterized vein deposits. The resulting absorbed dose rate at 1m above bedrock level as estimated using dose rate conversion factors (DRCF) fall within

the range of 70-500 $nGyh^{-1}$(Mun), 600-6000 $nGyh^{-1}$ (Uro) and 80-300 $nGyh^{-1}$(Kurun). At maximum, it corresponds to annual effective dose rate of 0.6, 8 and 0.4mSv, respectively. Uranium was the principal producer of the surface radioactivity at Uro and Kurun as it contributed 99.6% and 95% of the total absorbed dose whereas, in Jebel Mun the cause of radioactive anomaly was due to ^{40}K and ^{232}Th. Regression analysis showed no correlation between uranium concentration and other radionuclides. Although, radioactive equilibrium was not likely to occur in surface and near-surface geological environments, however, daughter/parent activity concentration ratios along uranium series, ^{234}U:^{238}U, ^{226}Ra:^{238}U, ^{230}Th:^{234}U, ^{210}Po:^{234}U do not differ from unity in both Uro and Kurun deposits.

In Ariab (Eastern Sudan) calculations of individual effective dose per annum have been made from the activity concentrations of dominant gamma-emitting radionuclides from uranium and thorium decay chains in ore, solid waste (heap) and soil samples collected from Adassedakh and HadalAuatib gold mines (Sam *et al*., 2000). Measurements were performed using a high-resolution gamma spectrometer. Independent of location, the data showed that the activity concentration for ^{226}Ra and ^{232}Th increased in the order: soil>spoil heap>ore. This order basically confirms that the activity levels in the heap were low relative to natural background (i.e. soil samples), and thus the expected contribution in enhancement of natural background radiation was correspondingly low.

The concept of concentration ratio (CR) has been applied to quantify the degree of accumulation of radionuclides in the solid waste (heap). The calculated CR values revealed that ^{232}Th was most accumulated while there was no accumulation of ^{40}K. Theabsorbed dose rates in air at a height of 1 m as estimated using DRCF from activities of ^{214}Pb, ^{214}Bi, ^{212}Pb, ^{228}Ac, ^{208}Tl and ^{40}K ranged from 6.6 to 32.3 $nGyh^{-1}$ (Adassedakh), and 2.2 to 26.1 $nGyh^{-1}$ (HadalAuatib). The principal contributors to the total dose rate were ^{40}K, ^{214}Bi and 228Ac which generate almost 90%. The corresponding annual effective doses fall within the range: 0.04-0.20 μSvy^{-1} for Adassedakh and 0.01-0.16$\mu Sv.y^{-1}$ for HadalAuatib. Although, these estimates do not include the internal radiation burden due to inhalation of radon and its decay products, the values obtained were insignificant relative to the dose limit specified for occupational exposure of any worker.

In eastern Sudan, Elgash area, an evaluation of nutrients and other trace elements content in soil, plants and water samples in addition to radionuclides levels were conducted (Babikir*et al.*, 2000) in an area which was located between latitude 15.3-16.5 degree and longitude 36-37 degree. The sampling sites were surveyed using portable scintillometer held at one meter above the ground level.

Rock samples collected from Jebel Glusi and Alttaka, and soil samples from the river banks were Analyzed using gamma-ray spectrometry for their radioactivity content. It was found that the activity concentration of ^{226}Ra, ^{228}Ra and ^{40}K in soil samples ranged from 13.0-30.7 $Bqkg^{-1}$, 12.5-59.9 $Bqkg^{-1}$and 283.0-461.4 $Bqkg^{-1}$, respectively. The calculated dose rate due to gamma radiation from the ground at one meter height ranged between 23.5 and 37.5 $nGyh^{-1}$ with an average value of 37.5 $nGyh^{-1}$ (229.9 μSvy^{-1}). This showed that the level of radioactivity in the surveyed area lies within the worldwide range of normal background radiation.

In Western Sudan, (Mukhtar ,1991) has carried out an environmental monitoring study at Miri Lake which is identified as high level background natural radiation areas in Nuba Mountains. The study was conducted in and around a lake situated at south-west of Kadogili town. The lake is an artificial one, formed when a dam was built between two mountains to harvest rain water draining along KhorBerdab in the rainy season. The lake is formed on a Uranium-Thorium mineralization zone. Miri area is a populated area in which people live on what is grown in the area. They used lake and well water for drinking and irrigation. Food, water and soil samples were collected and measured for their radioactivity using high resolution gamma-spectrometry, laser flourimetry, X-ray fluorescence, gross alpha-beta measurement and alpha spectrometry. Exposure of population to the external and internal radiation was estimated. A sodium iodide scintillation detector was used for measurement of the external exposure. Environmental samples were collected, processed and measured. Samples from places of normal background radioactivity were measured to serve as reference level for comparison. From these results the author concluded that Miri lake area was an elevated natural radioactivity level. The level of elevation is in the range of 2.5-11 times greater than in places with normal background natural radioactivity. The upper limit of the average annual effective dose to the population was estimated at 39.5 mSv due to the external and ingested food and due to radon inhalation in the area.

In South part of Sudan, sanner, (Sam et al,2007), have conducted a study on calculation of absorbed gamma-dose rate in air at a height of 1 m above ground level from activity concentrations of gamma-emitting radionuclides in arable soil samples collected from eight locations within Sinnar State using the published Dose Rate Conversion Factors. The average value of absorbed dose rate in air at a height of 1 m for all sampled location was 39±7 $nGyh^{-1}$ which was a characteristic of normal background radiation areas; the corresponding annual effective dose was 47.8±6 mSv y^{-1}. The major contribution to the total absorbed dose rate comes from ^{232}Th, which amounts to 61%. Recalculation

of the absorbed dose rate-based gamma-energies of individual nuclides from uranium and thorium decay series and ^{40}K showed that the greater part of the absorbed dose from the uranium series was due to ^{214}Bi, whereas for the ^{232}Th series it was equally attributed to ^{228}Ac and ^{208}Tl.

In Northern Sudan, (Einas, 2012) has carried out assessment and GIS mapping of radioactivity in the Northern State. Activity concentration of ^{238}U, ^{232}Th , ^{40}K and ^{137}Cs in soil samples collected from different locations have been measured using high resolution γ-spectrometry. ^{137}Cs was found to be of very little contribution to the total exposure. Absorbed dose rate in air at a height of 1m from the ground was calculated using six sets of dose rate conversion factors and the corresponding annual effective dose was estimated, study area was lie within the worldwide range for normal background radiation areas. Additionally, (Wisal B. Hassan,2013) have been carried out Investigad for naturally occurring radionuclides in surface soils in selected regions of the Northern State of Sudan ,reported activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in different regions of the Northern State was found to be 82.6 ± 6.8, 26.0 ± 2.9 and 726.4 ±72.0 $Bqkg^{-1}$, respectively. The external absorbed dose rate in air at 1meter above ground was 84.6 ± 7.1 $nGyh^{-1}$. Witin The average annual effective dose was 103.7 ± 8.7 μSvy^{-1}.

Hatem Eltayeb ,(2005), comprehensive studied was carried out for the determination of different radionuclides activities in foodstuff consumed and evaluation of dose levels in different food stuffs were collected from eight states in Sudan (cereals, vegetables, meat, fruits, milk and fermented milk, baby milk, cans, spices, additives, others). The concentrations of different radionuclides in the food samples were determined by gamma - spectrometry using an HPGe detector. Radionuclides observed include: ^{212}Bi, ^{214}Bi, ^{134}Cs, ^{137}Cs, ^{40}K, ^{212}Pb, ^{214}Pb, ^{224}Ra, ^{226}Ra, ^{228}Th, ^{228}Ac, ^{208}Tl, ^{232}Th and ^{238}U. The activity concentration of these radionuclides were found in the following ranges: 0.51 - 19.42 $Bqkg^{-1}$, 0.47 - 12.13 $Bqkg^{-1}$, 0.5 - 1.29 $Bqkg^{-1}$, 0.001 - 3.41$Bqkg^{-1}$, 19.25 – 2521.82$Bqkg^{-1}$, 0.08 - 6.84$Bqkg^{-1}$, 0.02 - 6.87 $Bqkg^{-1}$, 6.08 - 32.02 $Bqkg^{-1}$, 0.03 - 21.53 $Bqkg^{-1}$, 0.92 - 26.77 $Bqkg^{-1}$, 0.91- 12.00 $Bqkg^{-1}$, 0.14 - 2.58 $Bqkg^{-1}$, 0.03 - 9.65 $Bqkg^{-1}$and 0.82 - 5.27 $Bqkg^{-1}$respectively. High concentrations were typically found in Portulaca; the lowest concentrations were found in barley and bread additives. The annual effective dose due to the different foodstuff estimated was found to be 2.78 ±0.44 $mSvy^{-1}$ and 1.18 ± 0.18 $mSvy^{-1}$ for age categories 7-12 y and > 17y respectively.

In South Kordofan, centeral Wast Sudan, (I.A.Alnour,2012),study Was surveyed on natural radioactivity of ^{214}Pb, ^{214}Bi in ^{238} U series and ^{208}TI, ^{228}Ac in ^{232} Th series collected from the state of southern Kordofan (Kadugli), Sudan has been carried out by using γ-ray spectroscopy technique. The gamma-ray spectra have been measured for daughter decaying of ^{238} U and ^{232} Th series. Elemental and activity concentrations were found to be 1.41±0.02 ppm and 17.41±0.19 Bqkg^{-1} for ^{214}Pb, 1.66±0.02 ppm and 25.60±0.21 Bqkg^{-1} for ^{214}Bi and 9.56±0.11 ppm and 38.81±0.43 Bqkg^{-1} for ^{208}TI 8.55±0.06 ppm and 34.71±0.23 Bqkg^{-1}, ^{228}Ac, respectively. Moreover, average activity concentrations of these radio-nuclides for granite samples have been compared with the typical values of different countries.

InUNSCEAR (1982 and 1988) a value of 2.4 mSv was quoted for the population living at Places of normal background radioactivity. The maximum annual committed effective dose equivalent of 5 mSv was recommended by the ICRP. This recommendation was justified by comparison with normal natural background radiation which has a value of 2 mSv. The value presently recommended by the ICRP for the principal limit for members of the public is 1μSv.

Various studies concerning radioactivity bound to soil were carried out in Worldwide, in Saudi Arabia a study was Measurement Radioactivity and Radiation Dose assessments in Soil from Albaha Region, Saudi Arabia, (J. H. Al-Zahrani, 2012). That reported The activity concentration and the gamma absorbed dose rates of the terrestrial naturally occurring radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were determined in soil samples collected from twenty different locations of Albaha region in Saudi Arabia, were performed using a NaI(Tl) gamma-ray spectrometer. The typical concentrations of ^{226}Ra ,^{232}Th and ^{40}K were found in surface soil samples ranged from 30.3±1.6 (sample18) to 45.3±1.9 (sample3) Bqkg^{-1} and from 26.0±1.8 (sample 17) to 37.5±1.8 (sample 18) Bqkg^{-1} and 263.2±6.4 (sample 4) to 434.9±5.4 Bqkg^{-1} sample 13) with overall mean values of 37 Bqkg^{-1} ,32 Bqkg^{-1} and 343 Bqkg^{-1}, respectively. The mean radium equivalent (Raeq) and outdoor radiation hazard index (Hex) for the area under study were determined as 116 Bqkg^{-1} and 0.29 respectively. The absorbed dose rate due to three primordial radionuclides lies in the range from 43to 60.3 nGyh^{-1} with a mean of 50 nGyh^{-1}, which yields the annual effective dose of 63 μSvy^{-1} which is well below the permissible limit .The measured values are comparable with other global radioactivity measurements and are found to be save for public and environment .The baseline data of this type will almost certainly be of importance in making estimations of populations exposure.

In Pakistan wasr reported Measurement of naturally occurring/fallout radioactive elements and assessment of annual effective dose in soil samples collected from four districts of the Punjab Province, Pakistan using a P-type coaxial high purity germanium (HPGe) c-ray spectrometer, (S. U. Rahman et at.,2010).The specific activities of ^{226}Ra,^{232}Th and ^{40}K of the soil samples ranged from 26.02 ± 7.11 to 93.54 ± 8.13 Bqkg^{-1}, 29.34 ± 2.58 to 114.41 ± 2.80Bqkg^{-1}and 348.15 ± 3.20 to 752.98 ± 4.20 Bqkg^{-1} , respectively .Activity due to ^{137}Cs was observed in some locations which ranged from 0.4 ± 0.2 to 7.8 ± 0.3 Bq kg^{-1}. From the measured activity concentrations, radium equivalent activity concentrations were determined followed by calculations of mean absorbed dose rate and mean annual effective dose for the inhabitants of the studied area. The mean radium equivalent activity, internal and external hazard indices values came out to be 179.26 ± 11.93Bqkg^{-1}, 0.64 ± 0.05 and 0.48 ± 0.03, respectively Indoors and outdoors average annual effective dose values were found to be 0.42 ± 0.03 and 0.10 ± 0.01 mSv, respectively. Present data have been compared with the published data for other parts of the world and found to be safe for public and environment.

In Spain a programme of studies and surveys of natural radiation and radioactivity was organized to determine the concentrations of natural radionuclides in soil (Quindos *et al*.,1994). The results showed that the averages and ranges of concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil in most autonomous regions and nationally were higher than the world figures reported by (UNSCEAR ,1988) (world average concentrations of 30, 25, and 370 Bqkg^{-1} for ^{226}Ra,^{232}Th, and ^{40}K respectively and typical ranges were 15-70 Bqkg^{-1} For ^{226}Ra, 7-50 Bqkg^{-1} for ^{232}Th, and 100-700 Bqkg^{-1} for ^{40}K). Only the regions of Andalucia, Baleares, Murcia, Navarra, and PaisValenciano showed results comparable to the typical UNSCEAR values for the entire world, except for the range of the ^{40}K concentrations measured in the region of Andalucia, whose upper limit was more than double that given by UNSCEAR. In relation to the geological structure of the country, the region of lower average concentrations of ^{226}Ra,^{232}Th, and ^{40}K in soil match those areas that essentially consist of recent marine sediments (mainly limestones , marbles, and clays) ranging in age from the Late Oligocene to the present.

In Mexico evaluated natural gamma radioactivity was made in Mexico to determine the concentrations of natural radionuclides in soil(Davila *et al*.,2003). Twenty soil samples collected in the cities of Zacatecas and Guadalupe and their suburban areas in the Mexican state of Zacatecas were analyzed by gamma-ray spectrometry to determine the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K. Conversion factors were used to calculate the dose to the population from outdoor exposure to terrestrial gamma rays. The measured activity concentration of ^{226}Ra varied from 11 to 38 Bqkg^{-1},

the activity concentration of ^{232}Th varied from 8 to 38 Bqkg^{-1}. The activity concentration of ^{40}K was in the range of 309-1,049 Bqkg^{-1}. The overall populations mean outdoor terrestrial gamma dose rate was 44.94 nGyh^{-1}.

In Cyprus a survey was carried out to determine activity concentration levels and associated dose rates from the naturally occurring radionuclides ^{232}Th, ^{238}U, and ^{40}K, in the various geological formations appearing throughout the geographically accessible area of Cyprus (Tzortzis*et al.,* 2004), by means of high-resolution gamma ray spectrometry. From the measured spectra, activity concentrations were determined for ^{232}Th (range from1.0x10-2 to 39.8 Bqkg^{-1}), ^{238}U (from 1.0x10-2 to 39.3 Bqkg^{-1}) and ^{40}K (from 4.0x10^{-2} to 565.8 Bqkg^{-1}). Gamma absorbed dose rates in air outdoors were calculated to be in the range of 1.1x10^{-2} - 51.3 nGyh^{-1}, depending on the geological features, with an overall mean value of 8.7 nGyh^{-1}and a standard deviation of 8.4 nGyh^{-1}. This value was by a factor of about 7 below the corresponding population weighted world-averaged value of 60 nGyh^{-1} reported by (UNSCEAR, 2000), and one of the lowest that has been reported from similar investigations worldwide. Assuming a 20% occupancy factor, the corresponding effective dose rates outdoors equivalent to the population were calculated to be between 1.3x10^{-2} and 62.9 μSvy^{-1}, with an arithmetic mean value of 10.7 μSvy^{-1} and a standard deviation of 10.3 μSvy^{-1}.

In Bangladesh the studied have been estimated and Assessment of Natural Radioactivity and Radiation Hazard in Soil samples collected from different Upazila of Rajbari district of Bangladesh were analyzed by gamma-ray spectrometry (R.Khatun et at.,2013) The average natural radioactivities of ^{238}U, ^{232}Th and ^{40}K have been measured as29.03±5.67 Bqkg^{-1}, 50.91±10.17 Bqkg^{-1} and 535.32±89.19 Bqkg^{-1} respectively. To estimate health effect due to the activity of those radionuclides, the radium equivalent activity (Ra absorbed dose rate (D) and effective dose have been calculated and compared to the world average values. The results are also compared with the literature values reported for other regions of the world and found that the soil of the study area are not hazards by the radiation and does not pose any harmful effect to the environment. The outcome of this study may provide valuable information about radiation hazard and also may take part in the monitoring of environmental radioactivity.

In the central and eastern region of the Brazilian state of Rio Grande do Norte, 51 soil samples were collected to a depth of 30 cm (Malanco*et al*., 1993). Concentrations of background radionuclides in soil samples were determined by gamma ray spectrometry with an HPGe detector. The average concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the surveyed soils were 29.0 ±19.4 Bqkg^{-1} 46.6 ± 36.2 Bq

kg^{-1}, and 677.8 ± 434.9 Bqkg-1 respectively. The bedrock of Sanata do Matos (Rio Grando do Norte) showed fairly high radioactivity (90 $Bqkg^{-1}$ of ^{226}Ra, 285.6 $Bqkg^{-1}$ of ^{232}Th and 1.414 $Bqkg^{-1}$ of ^{40}K).

Some areas in India have high levels of natural radiation due to presence of monazite along with other heavy minerals such as ilmenite, rutile, zircun, garnet, etc. The monazite contains approximately 9% thorium and 0.3% uranium. Over 140,000 in habitants in Kerala, on the southwest coast of India, receive an annual average dose of 15-25 mGy). The average life span of the inhabitants of Kerala is 72 years while for all India it was only 54 years. A comprehensive study on the residents of HLNRAs of Kerala showed no evidence that cancer incidence is consistently higher because of the levels of external gamma radiation exposure in the area. In another study the incidence of congenital malformations in the densely populated monazite bearing sands of Kerala, the stratification of newborns with malformations, stillbirths or twinning showed no correlation with the natural radiation levels in different areas. No significant differences were observed in any of the reproductive parameters between 26,151 newborns from HLNRAs and 10,654 from a NLNRA (Mortazavi and Karam, 2002).A health survey study on the inhabitants of HLNRAs of Yangjiang, China was started in 1972. In HLNRAs of Yangjiang County in China (annual doses were about 330 mR) 39 it has been indicated that mortality from all cancers and those from leukemia, breast and lung were not higher than that of the control area (110 mRy^{-1}). Furthermore, it was shown that when samples of circulating lymphocytes taken from the inhabitants were tested in vitro for mitotic response to phytohemagglutinin (PHA) and the degree of unscheduled DNA synthesis (UDS), there were higher responsiveness and UDS rates in the HLNRA samples than in those from the control area. It was found that in a HLNRA in China the cancer (non-leukemia) mortality was 14.6% lower than in Normal Background Radiation Areas (NBRA), and the leukemia mortality among men was 15% lower and among women 60% lower. No difference in the frequency of various genetical diseases was observed between Chinese HLNRA and NBRA. To date, based on the data as: cancer mortality from 1,008,769 person-years in HBRA and 995,070 person-years in CA; hereditary diseases and congenital malformations from 13,425 subjects in HBRA and 13,087 subjects in CA; human chromosome aberrations, and immune function of the inhabitants, no detrimental effect associated with the high levels of natural radiation detected. On the contrary the mortality due to all cancers in HLNRAs was generally lower than that in the control NBRA. However, the difference was not statistically significant (Mortazavi and Karam, 2002).

Also in India the Study Was Evaluated natural gamma radiation and absorbed gamma dose, 31 soil sample and 14 rocks sample were collected form Perambalur district (K. Jeevarenuka, 2014). The activity concentrations and absorbed gamma dose of primordialradionuclides ^{238}U,^{232}Th and ^{40}K were determined employing gamma-ray spectrometry. The soil samples registered relatively a higher mean value of 13.2 $Bqkg^{-1}$ for ^{238} U, 66 $Bqkg^{-1}$ for ^{232}Th and 340.3 $Bqkg^{-1}$ for ^{40}K as compared to mean values for rock samples (^{238}U—8.0 $Bqkg^{-1}$;^{232}Th—65.1 $Bqkg^{-1}$;^{40}K—199.1 Bq kg^{-1}). The mean absorbed gamma dose rate for soil (61.4 nGy h^{-1}) marginally exceeded the prescribed limit of 55 nGy h^{-1} while, rocks registered the mean absorbed gamma dose rate of 10.4 $nGyh^{-1}$. The meanradium equivalent activity was distinctly higher in soil (130.6 Bq kg^{-1}) than in rock (20.0 Bq kg^{-1}). However, these values were lower than the limit (370 Bq kg^{-1}) set by OECD for building materials. It is evident from the data that the soil and rocks do not pose any radiological risk for house constructions in Perambalur district.

In Nigeria Studed Natural radioactivity measurements in rock samples of Ondo and Ekiti States (I.R. Ajayi et at., 2001). The concentrations of the natural radionuclides namely ^{40}K, ^{232}Th and ^{238}U in 44 different rock samples around Ondo and Ekiti states have been determined using an Nal(TL) detector coupled to a computerized ACCUSPECMCA (Multichannel Analyzer) Installation. Gamma spectrometric analyses were performed and the concentrations obtained for each of the radionuclides expressed in $Bqkg^{-1}$ are 4.75120.091, 13.37620.0197, and3.30820.017 for ^{40}K, ^{238}U and ^{232}Th, respectively. The mean absorbed dose rate is 8.13920.427$nGyh^{-1}$ at 1.0 m above the ground level. These results indicate that the radioactivity in these rocks is very low.

In Cyprus a survey was carried out to determine naturally occurring radioactive samples characteristic geological rocks using high-resolution gamma-ray spectroscopy (Michalis Tzortzis et at.,2003). The terrestrial gamma radiation in all the predominant types of geological rock formations appearing from the measured gamma-ray spectra, activity concentrations were determined for ^{232}Th (range from 1.3 to 52:8$Bqkg^{-1}$), ^{238}U (from 0.9 to 90:3$Bqkg^{-1}$) and ^{40}K (from 13 to 894 Bq kg^{-1}). Elemental concentrations mean values of (2:8 ± 0:7) ppm, (1:3 ± 0:3) ppm and (0:6 ± 0:1) % were extracted, for thorium, uranium and potassium, respectively. Absorbed dose rates in air outdoors were calculated to be in the range of 0.1–50 $nGyh^{-1}$, depending on the geological features, with an overall mean value of (14:7±7:3) $nGyh^{-1}$. The corresponding effective dose rates per person outdoors were estimated to be between 0.1 and 61:4 μSvy^{-1}, assuming a 20% occupancy factor.

In South Afirca the aim of this study was to investigate the potential radiological impact of foodstuffs grown Ina catchment area influenced by mining and mineral reprocessing industries in

South Africa. Natural radionuclides were determined in a number of foodstuffs harvested from and/or grown in the area. Theradionuclides were measured by non-destructive techniques such as Instrumental Neutron Activation Analyses (INAA) and low background gamma spectrometry. The estimated dose for the adult age group, resulting from consumption of these foodstuffs, was evaluated. (I .Louw 2011). Sensitive measurement of three major radionuclides (in addition to ^{238}U,^{234}U,^{232}Th,^{226}Ra,^{224}Ra and ^{223}Ra) is necessary to calculate the estimated annual dose with a high degree of certainty i.e. ^{230}Th,^{210}Pb and ^{210}Po, while ^{231}Pa,^{227}Ac and ^{228}Ra also require improved sensitivity. In orderto evaluate the yearly dose due to an individual source at a screening level of 25 μSv/a, one is faced with a required lower limit of determination (LLD) of 0.1 to 0.5 $Bqkg^{-1}$ for certain foodstuffs. The assessment of natural radionuclides in foods allowed us to evaluate the items that present the highest risk to the population, and compare this to the limits established by the National Nuclear Regulator (NNR).From the public's point of view it is important to ensure the population that the contaminant levels in specific food as a result of mining activities, do not exceed the permissible limits. For the majority of the analyse foodstuffs, the estimated dose was less than 250 μSv/a. Overestimation of dose, due to poor measurement detection limits, was clearly indicated for some of the samples. For most of the analyse nuclides, suitable data for evaluation of the yearly dose at the screening level of $25\mu Svy^{-1}$ was obtained by broad energy gamma analysis of ashed samples. However, nuclides such as ^{230}Th, ^{210}Po and ^{231}Pa has to be analysed by radiochemical separation through acid destruction of dried foodstuffs followed by individual element separations to provide suitable data with a low enough LLD not to result in an overestimation of the calculated dose.

In Tanzanian was measured Radioactivity levels of staple foodstuffs products (maize and rice) from various localities of Tanzania and dose estimates (N .A. Mlwilo, 2007). The average activity concentrations of ^{40}K, ^{232}Th and ^{238}U in maize were 48.79 ± 0.11, 4.08 ± 0.01and 13.23±0.10 $Bqkg^{-1}$, respectively. In rice the concentrations of ^{40}K, ^{232}Th and ^{238}U were 24.67±0.03, 3.82±0.02 and 5.02±0.02 $Bqkg^{-1}$, respectively. ^{137}Cs was detected in only one sample collected in Zanzibar. The sample, with activity concentration of 5.57 ± 0.01$Bqkg^{-1}$, had been imported from Thailand. The relatively high average concentrations of the radionuclides in maize compared to rice may be attributed to the extensive use of phosphate fertilizers in maize production in Tanzania. Total annual committed effective doses due to total ^{232}Th and ^{238}U intakes as a result of consumption of staple foodstuffs for infants, children and adults were 0.16, 0.29 and 0.36 μSvy^{-1}, respectively, which are lower than the annual dose guideline for the general public.

CHATER THREE

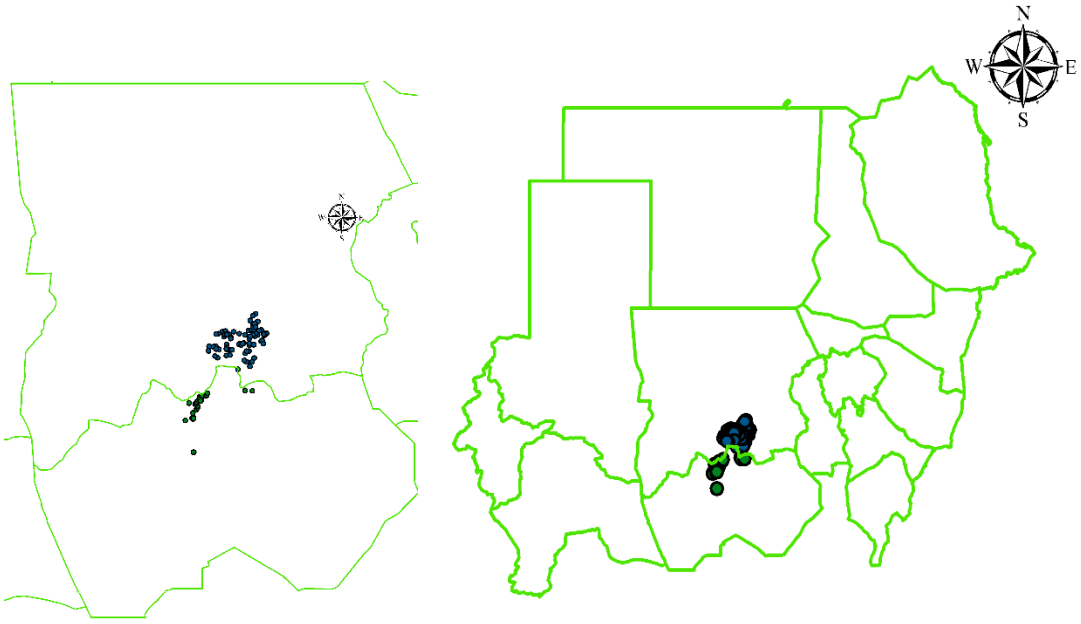
MATERIAL AND METHODS

3.1 Gamma-spectrometric analysis

About 500 grams of the powdered all samples were weighed in dry clean Marinelli beaker and stored for four weeks so as to allow in growth of gaseous ^{222}Rn and its short-lived decays products to reach secular equilibrium with long lived ^{226}Ra precursor in the sample. The samples were measured via γ-spectroscopy equipped with NaI (Tl) detector. Sample spectra were analyzed using winTMCA32 software package (provided by IAEA). ^{238}U was determined by means of its progeny photo peaks: ^{214}Bi (609 Kev) and ^{214}Pb (352 Kev). ^{232}Th was analyzed through its daughter photo peak ^{212}Pb (238 Kev). The activity concentration of ^{40}K and ^{137}Cs was determined by using 1460 Kev and 662Kev gamma line, respectively

3.1 The study area

Area under study is located in the south & North Kordofan State and lies between latitudes 29.32 and 31.49 ºE, and longitudes 11.47 and 12.08 ºN , 29.51 and 30.21 ºE latitudes and 12.47 -13.19 ºN as depicted in Figure(3.1):



Figure(3.1): Study area (North and South Kordofan States, Sudan) display sampling locations

3.3 Sample Collection and Preparation

3.3.1. Soil samples

A total of 114 soil samples were collected from various sites in Kordofan State At each sampling point, grass and tree leaves removed from the top of the soil surface before the soil was sampled. Three cores of the top soil were taken in depth of at 15cm, by using stainless steel sampler coordinating were recorded using GPS, are presented in Table 3.1

3.3.2 Rock samples

A total 31 samples of rock from different random locations around the sampling sites were collected, then crushed ground to fine powder and homogenized by passing through 2mm sieve weight 500gm, sealed plastic containers, and left for more than a month before counting by gamma-ray spectroscopy allow secular equilibrium, by using stainless steel sampler coordinating were recorded using GPS, are presented in Table 3.2

3.3.3 Staple food and vegetation Samples

A total of 29 samples of staple food and vegetation from different random locations around the sampling site were called, samples were cleaned, air dried for one week, placed in an over at 60^{o}c for 6 hour, samples crushed and homogenized by passing through 2mm test sieve, the dry weights were determined, samples were stored in plastic containers to reach secular equilibrium by using stainless steel sampler coordinating were recorded using GPS, are presented in Table 3.3

Table (3.1): Table Location names with their coordinates in soil samples -North Kordofan

Sample code	GPS reading		
	Latitude °E	Longitude °N	Alttitude (m)
Ob01	30.2639008	13.2118713	572
Ob02	30.2652741	13.1757712	569
Ob03	30.2693939	13.1503643	578
Ob04	30.2378082	13.1343164	589
Ob05	30.158844	13.0982049	567
Ob06	30.1011658	13.149027	587
Ob07	30.1506043	13.2078605	575
Ob08	30.1890564	13.2158821	571
Ob09	30.2192688	13.2158821	566

Ob10	30.2522278	13.1730969	577
Ob11	30.2055359	13.1543761	585
Ob12	30.2192688	13.2265773	568
JK01	30.3208923	13.0714522	571
JK02	30.3318787	13.0768029	581
JK03	30.3483582	13.0393451	553
Kh01	30.3483582	13.159725	587
Kh02	30.3620911	13.1517015	583
Kh03	30.3868103	13.1757712	583
Kh04	30.3868103	13.1677483	586
Kh05	30.3648377	13.1463524	586
Kh06	30.3565979	13.1623994	574
Kh07	30.170034	13.130907	564
Kh08	30.3181458	13.218556	555
Kh09	30.2910167	13.2093383	561
MO01	30.2330017	13.2586598	559
MO02	30.2384949	13.2853921	555
MO03	30.2110291	13.3067757	543
MO04	30.2110291	13.2559864	554
MO05	30.2714539	13.3308301	543
MO06	30.2275085	13.30143	554
MO07	30.1725769	13.346865	540
MO08	30.2467346	13.4377094	529
MO09	30.2390067	13.255455	567
MO10	30.2082825	13.410994	527
BJ01	30.2261353	12.8439377	534
BJ02	30.2173517	13.0226517	568
BJ03	30.1986694	12.7903748	527
Ka01	30.1245883	12.9362483	554
Ka02	30.1217217	12.7906067	555
Ka03	30.0923117	12.8088467	559
Ka04	30.1054833	12.9074667	564
Ka05	30.1583233	13.0174083	554
Ka06	30.1591367	13.0371533	571
Ka07	30.007782	12.6912535	570
Ka08	30.1670837	12.7287634	592
Ha01	30.1560974	12.9349684	531
Ha02	30.1245883	12.9362483	554
Ha03	30.0489807	13.0206141	563
Ha04	30.071885	13.0380533	550

Ha05	30.0215149	13.0313177	574
Ga01	30.0846863	13.0446966	555
Ga02	30.0520067	13.0185635	568
Ga03	30.0681733	13.0375717	563
Ey01	30.0217117	13.167275	589
Ey02	29.7935486	13.1944905	603
Ey03	29.8155212	13.1276295	627
Ey04	29.7441101	13.1677483	615
Ey05	29.7111511	13.1623995	524
Ey06	29.9501038	13.1944905	590
Ey07	29.8374939	13.2051865	596
Hz01	29.8539734	13.02329	628
Hz02	29.8579633	12.9880983	621
Hz03	29.85841	12.956805	622
Hz04	29.870975	12.953845	624
Hz05	29.8895617	12.9529133	619
Hz06	29.9093783	12.9532517	617
Hz07	29.9239517	12.9542683	610
Hz08	29.7523499	12.9617358	663
Hz09	29.7084045	12.9965292	690
Hz10	29.6122742	12.9992054	695
Hz11	29.606781	12.9403221	709
Hz12	29.6754456	12.993853	698
Hz13	29.705658	12.9644124	679
Ni01	29.8484802	12.967089	631
Ni02	29.8226	13.1565817	616
Ni03	29.8262	13.1570433	621
Ni04	29.8669283	13.1673333	609
Wm01	29.8916933	13.1579733	610
Wm02	29.8559633	13.1579733	600
UB01	29.9099717	13.1202933	610
UB02	29.90942	13.1035183	620
UB03	29.8484802	12.8733924	638
UB04	29.8979187	12.8814249	674
UB05	29.7276306	12.8466155	681
UM06	29.6946716	12.8680373	677
UB07	29.6040344	12.8787475	674

Table (3.2): Location names with their coordinates in soil samples -South Kordofan

Sample code	**GPS reading**		
	Latitude °E	Longitude °N	Alttitude (m)
Ka01	29.407034	11.5778	724
Ka02	29.403847	11.5791	723
Di01	29.443632	12.152434	629
Di02	29.457920	12.176435	616
Di03	29.457920	12.202610	605
Di04	29.425634	12.225013	623
Di05	29.438824	12.228811	629
Di06	29.34451	12.237153	638
TB01	29.446313	12.250946	635
TB02	29.468923	12.273334	623
Du01	29.484226	12.31893	622
Du02	29.50473	12.304019	649
Du03	29.516755	12.32608	611
Du04	29.569921	12.330851	579
Du05	29.483052	12.293116	610
Kr01	29.50518	12.268622	627
Kr02	29.500018	12.268625	620
Da01	29.2955	12.0033	706
Da02	29.3957	12.1070	673
Da03	29.4012	12.0343	674
Da04	29.4022	12.0426	699
Da05	29.3914	12.0403	680
Da06	29.3832	12.0331	691
Da07	29.3939	12.0243	681
Da08	29.4041	12.0333	671
Sh01	30.10054	12.4064	516
Sh02	30.1074	12.4024	574
Sh03	30.2003	12.4013	
Hm01	29.5913	12.3684	574
Hm02	29.5811	12.3428	724
Hm03	29.5910	12.3695	519

Table (3.3): Location names with their coordinates in rock samples -Jable Kordfan and Jable Dalanj

Sample code	**GPS reading**		
	Latitude °E	Longitude °N	Alttitude (m)
K01	30.2053	13.0439	610
K02	30.2055	13.0431	618
K03	30.2100	13.0412	610
K04	30.2057	13.0405	617
K05	30.2047	13.0411	622
K06	30.2040	13.0440	598
K07	30.2050	13.0439	602
K08	30.2054	13.0450	619
K09	30.2057	13.0444	602
K10	30.2072	13.0455	636
K11	30.2090	13.0482	600
JD01	29.3923	12.0340	696
JD02	29.3923	12.0345	691
JD03	29.3984	12.5425	668
JD04	29.3912	12.0344	691
JD05	29.3913	12.0337	695
JD06	29.3911	12.0336	694
JD07	29.3908	12.0332	702
JD08	29.3907	12.0326	698
JD09	29.3849	12.0375	690
JD10	29.3902	12.0324	698
JD11	29.3858	12.0315	700
JD12	29.3857	12.0320	694
JD13	29.3907	12.0318	696
JD14	29.3854	12.0254	695
JD15	29.3849	12.0251	688
JD16	29.3836	12.0254	692
JD17	29.3836	12.0259	697
JD18	29.3842	12.0303	700
JD19	29.3848	12.0302	700
JD20	29.3849	12.0375	690

3.4 Dose Calculation

The radiation effects in the air can be expressed in terms of the exposure rate or the absorbed dose rate in air at I m height. The absorbed dose rate ($nGyh^{-1}$)$\overline{D}$ was calculated from ^{238}U, ^{232}Th and ^{40}K activity concentration using different dose rate conversion factors (DRCFs) as given in Table (3.4). The absorbed dose rate was computed using the equation (3.1), and the annual effective dose equation (3.2):

$$\overline{D} = A \times \text{DRCFs} \quad (1)$$

Where: $\overline{D}$= absorbed dose rate , A = radioactivity Concentration in Bq kg^{-1}

DRCFs = dose rate conversion factors (nGyh-1 per Bqkg-1) as given in Table (3.4)

The evaluation absorbed dose rate in air (μSvy-1) was converted into annual effective dose ($\overline{H}$) using the conversion formula:

$$\overline{H}(\mu\text{Svy}^{-1}) = \overline{D}(nGyh^{-1}) \times 24\,h \times 365.25\,d \times 0.2 \times 0.7\,(Sv\,Gy^{-1}) \times 10^{-3} \quad (3.2)$$

Where: 0.7 $SvGy^{-1}$ is the conversion coefficient from absorbed dose in air to effective dose received by an individual, and 0.2 for the outdoor occupancy factor (UNSCEAR, 1993-2000).

3.4.1 Dose rate conversion factors (DRCFs)

Conversion factors from radionuclide activity in soil or bedrock into the ground component of absorbed dose rates in air have been estimated from photon transport calculation applied to infinite soil or bedrock and air media. Dose rate at a reference point for discrete photon energy strongly depends on attenuation effects in material between the source and the reference point. The gamma ray attenuation depends primarily on emitted photon energy. The numerical solution of this complex mathematical problem evaluates the effect of primary and scattered gamma rays in the ground and in the air. The ground component of dose rate to air in free air is the product of radionuclide specific activities in soil and/or bedrock with the sum of respective products between unit dose rates for each emitted photon energy and their emission intensity . DRCFs were derived through different approaches, the details of which will be summerzed in table (3.4).

Table (3.4) Dose rate conversion factors for some radionuclide used for calculation of absorbed dose (nGy h^{-1}) (Tzortzis et.al, 2002)

Nuclide	MC	MCNP	GEANT	UNSCEAR
^{238}U Series				
^{214}Pb	0.04413	0.04150	0.04342	
^{214}Bi	0.34156	0.33849	0.35554	
Total	0.38668	0.38092	0.39996	0.462
232Th Series				
^{212}Pb	0.01926	0.01796	0.01917	
Total	0.52389	0.51678	0.5437	0.604
^{40}K	0.03808	0.03780	0.03995	0.0417

CHAPTER FOUR

RESULTS AND DISCUSSION

Activity level of primordial radionuclide ^{238}U, ^{232}Th and ^{40}K in soil, rock and plant samples from different locations raoud North and South Kordofan states were measured and the result is summerzed in Tables 4.1 to 4.4. Statistical summary (mean±sd and range) of ^{238}U, ^{232}Th and ^{40}K were found to be 22.83±4.04 (18.94-26.53), 25.11±4.96 (19.08-31.41) and 284.31±80.45 (187.57-385.56) $Bqkg^{-1}$ respectively for soil samples in North Kordofon. Fallout nuclide ^{137}Cs was detected with very low concentrations 0.28±0.65 (0 – 1.62) $Bqkg^{-1}$, Comparing the range of ^{137}Cs level with dada from Libya 0.9 to 1.7 $Bqkg^{-1}$, Spain 10 to 60 $Bqkg^{-1}$, Jordan 1.5 to 2.6 $Bqkg^{-1}$, Egypt 1.6 to 19.1 $Bq{\cdot}kg^{-1}$, Yugoslavia1.5 to 28.4 $Bq{\cdot}kg^{-1}$,Greece 3.73 to1307 Bq. kg^{-1} , Sudan 2 to 26 $Bqkg^{-1}$, Central Sudan 0.2 to 0.9$Bqkg^{-1}$ and Northern Sudan 0.14 to 6.72 $Bqkg^{-1}$. Obviously the level of ^{137}Cs seem to be very low which implies negligible contribution to the total exposure from the environmental background radiation (Fig. 4.1, 4.2, 4.3 and 4.4). For soil samples of South Kordofan the levels of ^{238}U, ^{232}Th and ^{40}K were 22.08±3.64 (18.93-27.04), 28.99±4.46 (24.37-34.36) and 319.16±56.85 (253.16-378.66) respectively; and ^{137}Cs was 1.38±0.66 (0.71 – 2.17) Bq.kg-1 and comparable with North Kordofan values. It was observed that ^{137}Cs had increasing trend from northern to southern parts, it might be due to its leaching, and the reason could be attributed to differences in their geological nature. For rocks samples (^{238}U, ^{232}Th and ^{40}K) were found to be 23.56±2.11 (20.15-25.76), 29.57±4.33 (22.95-33.22) and 330.58±37.06 (278.04-375.87) Bq/kg), respectively , and for foodstuff samples (^{238}U, ^{232}Th ^{40}K) were found to be 4.67±0.88 (3.68-5.73), 4.49±1.39 (2.59-5.91), 326.36±130.32(191.4-477.26). The all vaule is compared with global data the estimated values in the areas can be considered as low-to-moderate background radiation. The world average values for ^{238}U , ^{232}Th and ^{40}K activity concentrations in soil are 35 (range: 16-110), 30 (range: 11-64), and 400 (range: 140-850) $Bq.kg^{-1}$ respectively (UNSCEAR 2000). Implies that most of the areas in North and some of South Kordofan state values fall within the range of lower background radiation. A common feature in any environmental radiation measurements is the considerable variation in soil radioactivity with location. The main factor influencing the concentration of the natural radionuclides in soil is the corresponding concentration in the soil forming rocks. In these measurements, standard deviation values indicate that the activity concentration of primordial radionuclides are highly scattered which indicates that the geological features in the study areas are not much differ. An attempt was made to draw radioactive maps for

both areas for the three selected nuclides (U, Th and K) in addition to the calculated absorbed dose using GIS program. This is presented in figures (4.9 to 4.12) which indicates that showed a trend of increase to the Maintains area for soil Sample and North Kordofan dose distribution is even across the study area, while South-West trend observed in South Kordofan part.

As we can see from (Tables 4.1 to 4.8) that ^{238}U, ^{232}The and ^{40}k levels in northern parts of the study area were slightly lower than other parts (South parts).

The absorbed gamma dose rate in air at a height of 1m from the ground surface was evaluated from the measured activity concentration using four sets of Dose Rate Conversion Factors (DRCFs) MC, MCNP, GAINT and UNSCEAR. The calculation of these DRCFs is based on different approaches. One approach is based on gamma-lines of individual gamma emitting radionuclide such as MC, MCNP, GAINT which we have used for estimating absorbed dose from the gamma-lines of ^{212}Pb (238 keV) for the ^{232}Th series, and from ^{214}Pb (352 keV) and ^{214}Bi(609 keV) for the ^{238}U series; and ^{40}K (1460 keV). Another approach is based on prevalent of secular equilibrium ^{238}U and ^{232}Th series and that the activity is homogeneously distributed at one meter depth. This is DRCF adopted by UNSCEAR publications. By applying equation (3.2) and the values of DRCFs as illustrated in Table (3.4), the measured specific activities of ^{238}U, ^{232}Th series and ^{40}K for each gamma-emitter were converted into absorbed dose rates in air (see the appendix, Tables 1 to 32). On the other hand, the corresponding annual effective dose was estimated using eq (3.3). Tables (4.11 to 4.18) show a statistical summary of absorbed dose rates in air ($nGyh^{-1}$) in some areas in south and north Kordofan state as calculated using different DRCFs with relative contributions of different nuclides to the total absorbed dose rate and the annual effective dose rate (μSvy^{-1}). Upon comparing the values obtained, it is obvious that all the currently available DRCFs which have been used here give values with unremarkable differences. However, the all sets of DRCFs seem as if they are two families (see tables 4.11, 4.13 , 4.15 and 4.17) for (MC &MCNP) formulas on one hand as they display values in soil (closed values), rock and foodstuff samples (25.60 ,25.26), (26.08,28.05) ,(28.80, 28.42) and (5.53 ,5.48) $nGyh^{-1}$ with corresponding annual effective doses of (31.20 , 30.99) ,(37.16, 34.42), (38.16,34.42) and (7.89,6.72)μSvy^{-1}, respectively. GANT based formulas namely UNSCEAR constitute one family as it is seen from the average values (26.57,29.61), (32.88,31),(33.95,33.34) and (5.00,6.16) $nGyh^{-1}$ with corresponding annual effective dose of (32.60,41.27), (38.53,39.81) ,(39.60,40.92), and (6.13, 7.56) μSvy^{-1} respectively. It should be noted that in the UNSCEAR reports, dose rate conversion factors are taken from Saito and Jacob (1995), which are 10 - 20 % higher than the more accurate values obtained recently by various Monte Carlo techniques (Tzortzis

et.al 2002) and that is apparent from these results. The relative contribution of the gamma-emitting radionuclides to the total absorbed dose rate in air at a height one meter was calculated. From these calculations it was observed the lowset contribution to the total dose rate is attributed to the ^{238}U series as depicted in (Fig. 4.9 and 4.11 ,4.13) in soil sample, ^{234}Th has the highest contribution to total absorbed dose rate (see Fig. 4.9, 4.11 and 4.12) in,Soil , rock samples respectively and for Food Stuff sample the highest contribution is ^{40}K . It might be useful to recall that changes in soil moisture content affect soil bulk density, so that the absorbed dose rate in air above the ground decreases with increasing soil moisture content.For ^{238}U series, however, this effect is superimposed on a change of ^{222}Rn emanation, which generally decreases with increasing soil moisture content. The absorbed dose rate in air from this decay chain is therefore essentially independent of soil moisture. As the shielding effect and the increased source effect roughly compensate. For ^{40}K and the ^{232}Th series, the absorbed dose rate in air is significantly reduced by soil moisture. Data reported by Beck et al. (UNSCEAR, 1977) show that the total external terrestrial annual doses in a given area during dry years generally averaged about 20 percent more than those for wet years (UNSCEAR, 1977).

There are some areas of markedly high absorbed dose rates in air throughout the world that are associated with thorium-bearing and uranium-bearing minerals in the soil (Table 4.9). Comparative study of absorbed dose rate in air obtained in this study - calculated on the basis of UNSCEAR DRCFs- is presented in Table (4.1 t0 4.8) with similar data from Sudan (Babikir et al. (2000), (Sam A.K et al (1997), (Sam A.K et al (2000), (Sam A.K et al(2002), (Sam A.K et al(2003), (Moawia(2006), North State(2007) North of Aljazeera State(2011), North Khartoum state(2011) and from different geographical regions (UNSCEAR, 2000). It is apparent that absorbed dose in air in some areas in South and north Kordofan state is below world-wide average characteristics for normal background areas and very far from the values of high natural radiation background areas.

Table (4.1): Activity concentration (Bqkg^{-1}) of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil samples- North Kordofan State.

Location	Number of sample	^{238}U	^{232}Th	^{137}CS	^{40}K
Hashaba	2	21.24±2.44	21.11±1.72	ND	313.23±42.48
Kazail	8	23.88±3.29	25.88±3.37	ND	308.94±35.83
Banjadid	3	29.79±5.48	30.72±5.92	0.67±1.17	297.50±34.68
Jable kofdofan	3	28.33±5.24	21.79±18.52	ND	449.10±146.73
ElObied	12	21.44±3.25	22.67±6.21	0.34±1.17	227.41±66.92
Khortaget	9	22.17±1.26	23.82±2.24	ND	340.40±131.27
Mosfa elobied	10	18.11±3.10	18.47±4.17	0.36±1.02	245.43±63.73
El eyarh	7	23.32±2.96	30.57±9.22	0.46±1.05	283.19±82.16
Abou haraz	13	20.86±3.06	28.83±4.16	0.28±0.73	266.69±93.18
Anumair	3	22.92±3.19	21.11±3.61	ND	234.56±176.15
Wad mkashvi	2	20.53±3.40	22.74±1.15	ND	179.38±109.23
Om bauid	7	18.92±4.44	24.77±1.17	0.75±1.41	245.19±30.48
Elgaka	3	23.07±0.59	26.93±1.31	1.08±1.87	283.19±44.59
Hilla sad	3	25.00±2.25	31.81±6.70	0.04±0.70	306.08±68.83
Total Averge ±SD	85	22.83±4.03	25.11±4.96	0.28±0.65	284.31±80.45
Min		18.94	19.08	ND	187.57
Max		26.53	31.41	1.62	385.56

Table (4.2): Activity concentration ((Bqkg^{-1}) of ^{238}U, ^{232}Th, and ^{40}K in soil sample-South Kordofan

Location	Number of sample	^{238}U	^{232}Th	^{137}Cs	^{40}K
Kazqil	2	28.48±7.92	30.04±4.25	2.42±0.57	321.81±42.48
Tayba	2	22.27±4.60	30.04±1.27	0.81±0.57	296.07±18.20
Showshaya	3	21.54±2.73	24.23±15.33	ND	320.38±60.88
Krkraah	2	21.55±3.02	26.58±0.21	2.63±0.29	296.07±54.61
Dubaibat	5	21.5±2.73	30.34±2.07	1.45±1.05	310.65±104.65
Dalanj	8	25.29±4.85	31.58±8.31	1.26±1.36	330.39±56.55
Al Hamadi	3	23.12±2.80	30.94±1.83	1.62±0.81	346.12±44.04
El Dilema	6	18.39±4.18	28.19±2.42	0.88±0.65	331.82±73.35
Total Averge±SD	31	22.08±3.64	28.99±4.46	1.38±0.66	319.16±56.85
Min		18.93	24.37	0.71	253.16
Max		27.04	34.36	2.17	378.66

Table (4.3): Activity concentration (Bqkg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in rock samples -North Kordofan and South Kordofan

Location	Number of sample	^{238}U	^{232}Th	^{40}K
Jable Kordofan	11	23.31±3.19	29.52±2.80	313.62±39.21
Jable Bala	4	24.92±0.73	32.44±1.61	336.83±34.59
Jable Kogoer	4	21.21±3.16	24.11±14.77	330.39±51.25
Jable Belengokaa	5	23.87±1.55	31.36±1.67	331.25±19.76
Jabl Dash	7	24.50±1.94	30.42±0.81	340.81±40.47
Total Averge±SD	31	23.56±2.11	29.57±4.33	330.58±37.06
Min		20.15	22.95	278.04
Max		25.76	33.22	375.87

Table (4.4): Activity concentration (Bqkg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in foodstuff samples South Kordofan

Type of food	Number of sample	^{238}U	^{232}Th	^{40}K
Maize	5	4.61±0.42	4.78±2.86	530.02±168.59
Cordia africana	*5*	3.87±0.96	3.90±1.94	319.48±160.66
Portulaca	5	4.46±0.94	4.70±0.95	301.82±116.28
Okra	5	5.40±1.14	4.94±1.04	348.93±164.31
Molokhia	5	4.51±0.58	4.54±0.53	295.93±156.19
Peanuts	29	5.14±1.22	4.08±1.00	161.95±15.90
Total Averge ±SD		4.67±0.88	4.49±1.39	326.36±130.32
MIN		3.68	2.59	191.4
MAX		5.73	5.91	477.26

Table (4.5): Activity concentrations (Bqkg^{-1}) of gamma emitters from ^{238}U, ^{232}Th series, ^{40}K and ^{137}Cs in soil samples North Kordofan

Location	**Number of sample**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**^{137}Cs**
Hashaba	2	21.11±1.72	17.12±2.50	19.11±2.89	313.23±42.48	ND
Kazail	8	25.88±3.37	20.51±3.61	21.84±3.63	308.94±35.83	ND
Banjadid	3	30.72±5.92	28.72±10.40	28.21±7.52	297.50±34.68	0.67±1.17
Jablekofdofan	3	21.79±18.52	28.72±6.03	26.84±5.96	449.10±146.73	ND
ElObied	12	22.67±6.21	16.82±3.51	16.95±4.12	227.41±66.92	0.34±1.17
Khortaget	9	23.82±2.24	19.61±0.97	18.81±1.33	340.40±131.27	ND
Mosfa elobied	10	18.47±4.17	18.12±9.28	15.36±2.21	245.43±63.73	0.36±1.02
El eyarh	7	30.57±9.22	17.88±3.62	21.35±4.79	283.19±82.16	0.46±1.05
Abou haraz	13	23.35±4.16	19.02±3.56	18.59±5.11	266.69±93.18	0.28±0.73
Anumair	3	21.11±3.61	15.94±2.13	15.70±3.80	234.56±176.15	ND
Wad mkashvi	2	22.74±1.15	16.53±1.67	17.74±3.86	179.38±109.23	ND
Om bauid	7	24.77±1.17	14.84±5.34	15.01±6.38	245.19±30.48	0.75±1.41
Elgaka	3	26.93±1.31	18.89±0.59	20.47±2.05	283.19±44.59	1.08±1.87
Hilla sad	3	31.81±6.70	24.00±3.75	25.48±2.40	306.08±68.83	0.04±0.70
Total Averge±SD	85	24.7±4.96	19.77±4.07	20.10±4.00	284.31±80.45	0.28±0.65
Min		19.08	15.51	14.97	187.57	ND
Max		31.41	25.76	24.79	385.56	1.62

Table (4.6): Activity concentrations (Bqkg^{-1}) of gamma emitters from ^{238}U, ^{232}Th series and ^{40}K in soil samples South Kordofan

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K
Kazqil	2	34.72±9.47	29.81±24.62	25.59±3.38	321.81±42.48
Tayba	2	29.84±11.77	18.00±6.26	18.17±6.27	296.07±18.20
Showshaya	3	30.05±11.71	19.67±12.29	20.70±5.56	320.38±60.88
Krkraah	2	39.18±3.73	20.66±4.17	17.40±13.03	296.07±54.61
Dubaibat	5	27.45±7.88	18.06±5.41	16.11±3.29	310.65±104.65
Dalanj	8	28.93±4.32	23.90±12.25	20.39±5.16	330.39±56.55
Al Hamadi	3	24.09±0.62	20.46±4.43	17.97±3.43	346.12±44.04
El Dilema	6	24.77±1.98	12.20±7.82	14.79±4.72	331.82±73.35
Total Averge ±SD	31	29.88±6.44	20.35±9.66	18.89±5.61	319.16±56.85
Min		23.55	11.8	13.06	253.16
Max		35.73	31.06	23.46	378.66

Table (4.7): Activity concentrations (Bqkg^{-1}) of gamma emitters from ^{238}U, ^{232}Th series and ^{40}K in Rocks samples -North and South Kordofan

Location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K
Jable Kordofan	11	26.10±7.89	19.64±4.41	20.78±4.53	313.62±39.21
Jable Bala	4	29.95±5.12	22.87±1.31	19.45±1.62	336.83±34.59
Jable Kogoer	4	30.35±2.26	18.89±5.60	20.64±4.26	330.39±51.25
Jable Belengokaa	5	29.80±2.31	21.84±2.67	18.43±2.77	331.25±19.76
Jabl Dash	7	29.18±2.17	21.92±2.03	21.16±3.72	340.81±40.47
Total Averge ±SD	31	29.08±3.95	21.02±3.20	20.09±3.38	330.58±37.06
Min		23.96	15.7	15.15	278.04
Max		34.27	24.08	24.7	375.87

Table (4.8): Activity concentrations (Bqkg^{-1}) of gamma emitters from ^{238}U, ^{232}Th series and ^{40}K in foodstuff samples South Kordofan

Type of food	Number of sample	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**
Maize	5	4.78±2.86	3.83±1.20	5.39±0.48	530.02±168.59
Cordia africana	*5*	3.90±1.94	3.02±1.66	4.72±1.58	319.48±160.66
Portulaca	5	4.70±0.95	3.13±0.97	5.79±2.00	301.82±116.28
Okra	5	4.94±1.04	4.88±2.48	5.93±0.56	348.93±164.33
Molokhia	**5**	4.54±0.53	3.37±1.12	5.66±0.77	295.93±156.19
Peanuts	4	4.08±1.00	4.21±1.45	6.06±1.10	161.95±15.90
Total Averge± SD	29	4.49±1.39	3.74±1.48	5.59±1.08	326.36±130.33
MIN		2.59	2.23	4.04	191.4
MAX		5.91	5.71	6.85	477.26

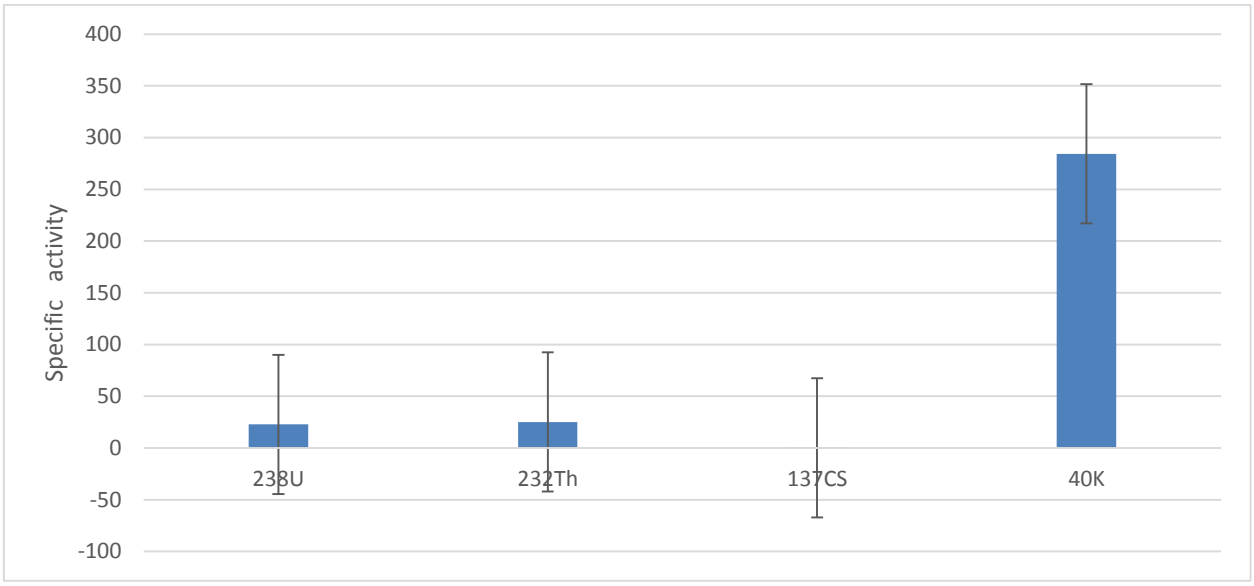


Figure (4.1): Average activity concentrations of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in Soil samples from North kordofan

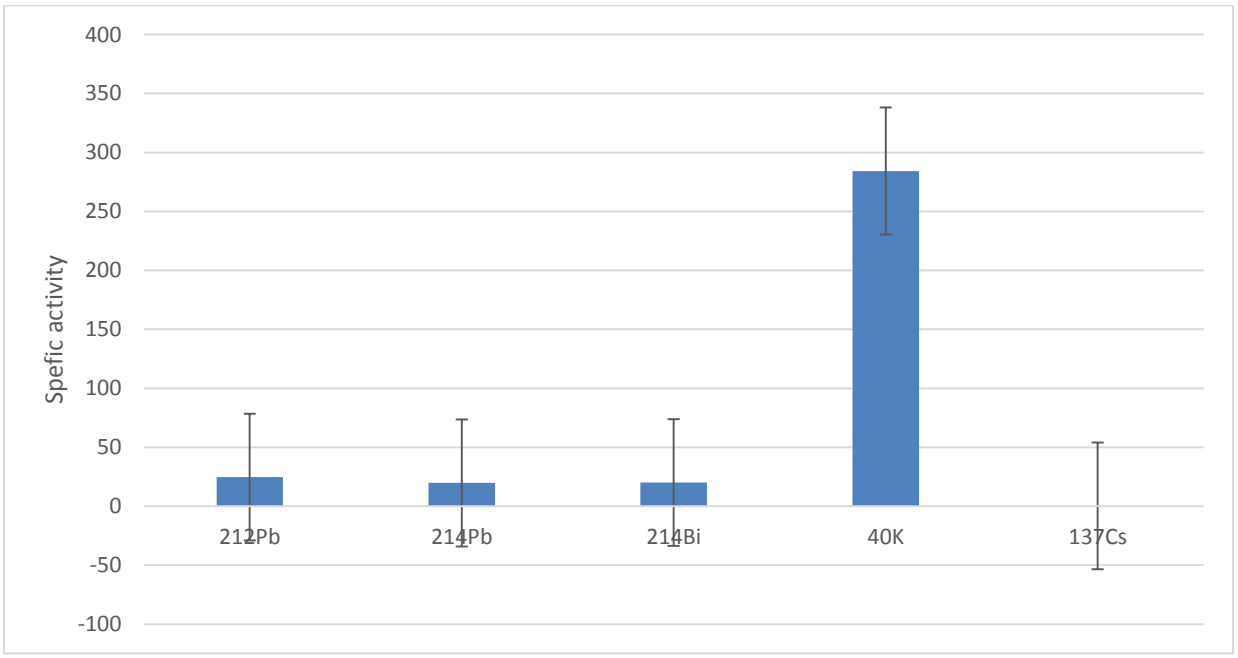


Figure (4.2): Average activity concentrations of ^{238}U, ^{232}Th series, ^{137}Cs and ^{40}K in Soil samples from North kordofan

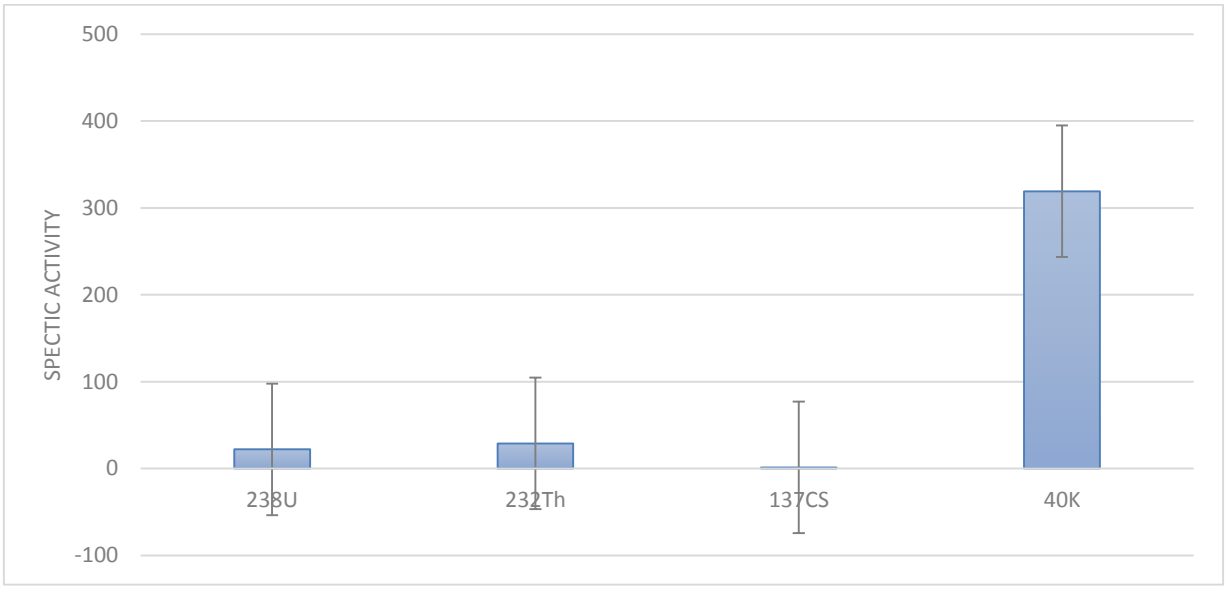


Figure (4.3): Average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Soil samples from South kordofan

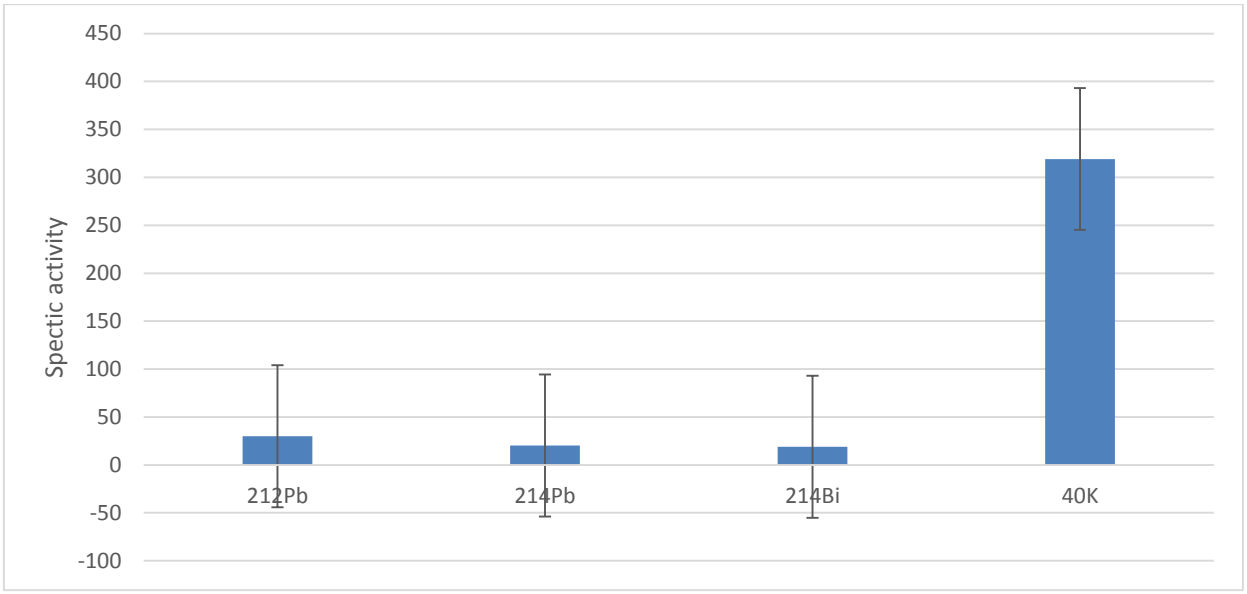


Figure (4.4): Average activity concentrations of ^{238}U, ^{232}Th series and ^{40}K in Soil samples from South Kordofan

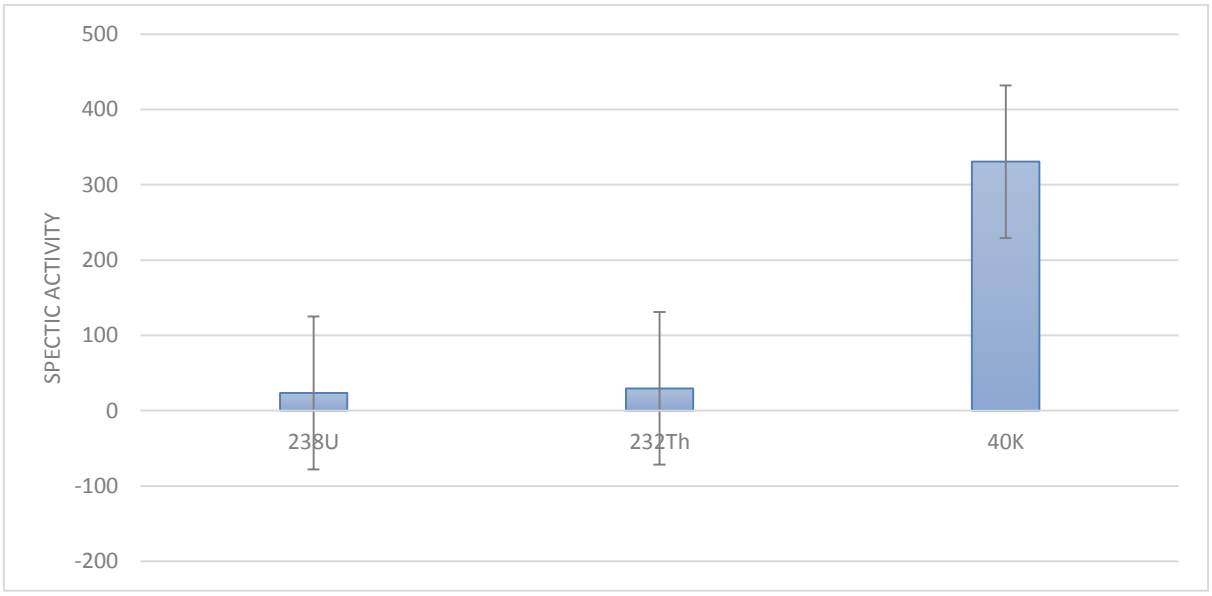


Figure (4.5): Average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in rock samples

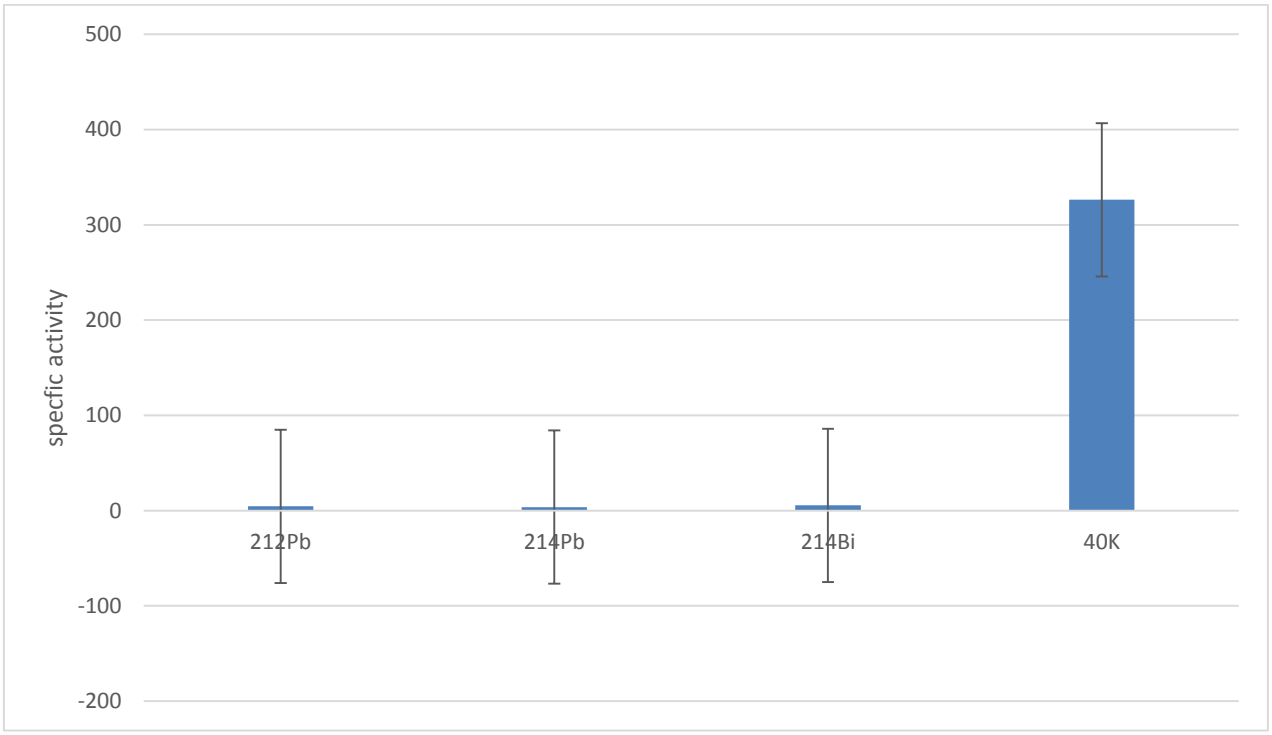


Figure (4.6): Average activity concentrations of ^{238}U, ^{232}Th series and ^{40}K in Rocks samples

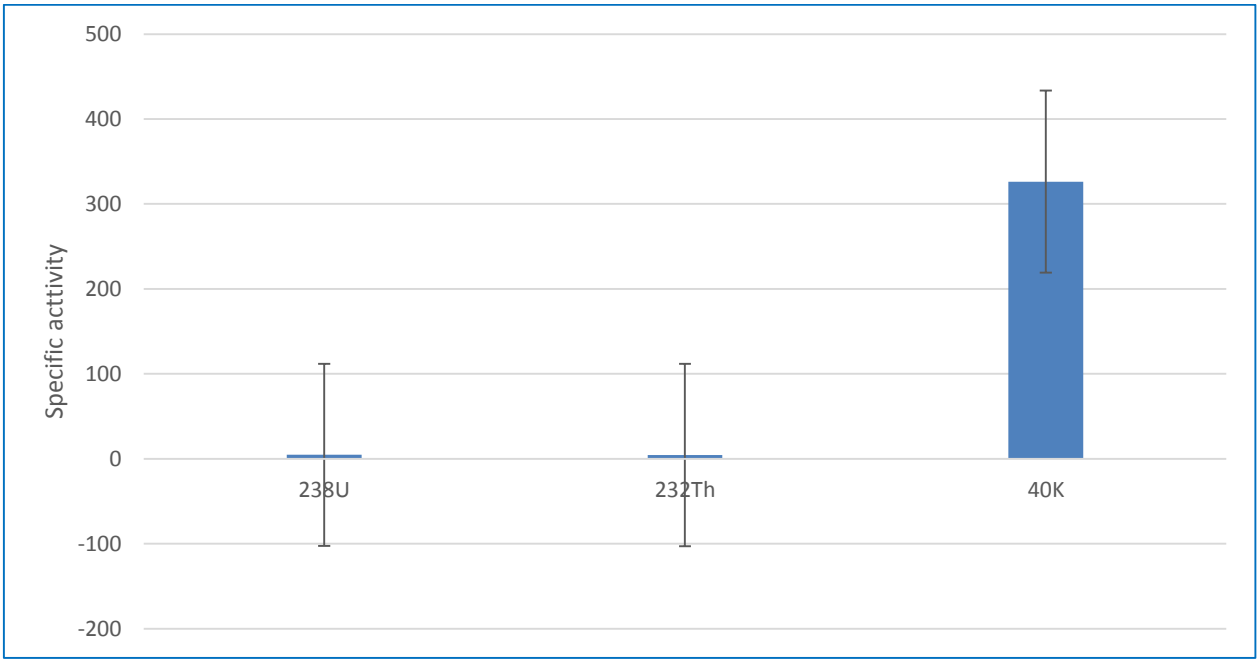


Figure (4.7): Average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in foodstuff samples

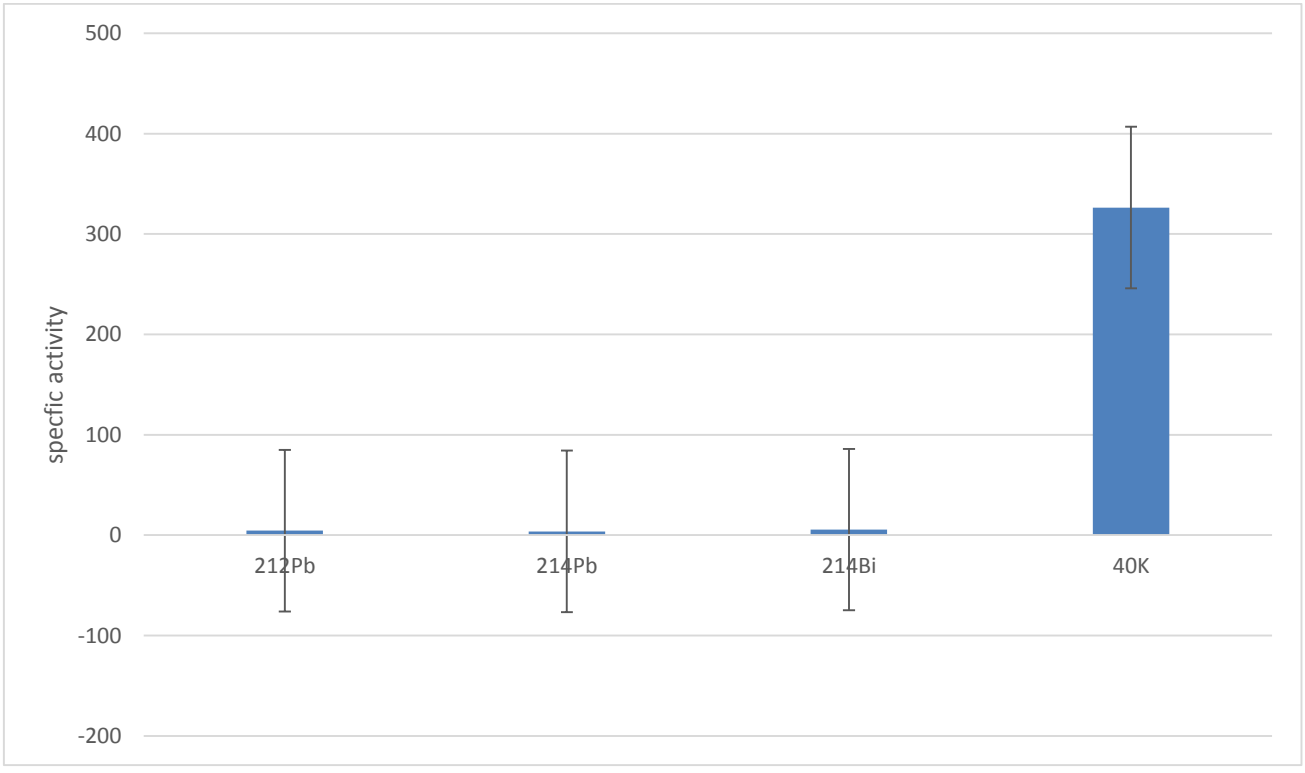


Figure (4.8): Average activity concentrations of ^{238}U, ^{232}Th series and ^{40}K in foodstuff samples

Table (4.9): Comparison of absorbed dose rate in air at 1 m height (derived using UNSCEAR DRCFs) with similar data from Sudan and different Countries:

Location	Absorbed dose rate (nGy/h)
Current Study	
Soil samplesNorth kordofan	4.49 -231
Soil sample South kordofan	3.9- 93
Rock samples	3.39- 3.34
Plant samples	1.98-6.16
Sudan	
Elgash area	37.5
Sinnar	38.80
Adassedakh	66-32.3
Hadal Auatib	2.2-26.1
From various locations	45
Jabel Mun	200
Uro	1900
Kurun	190
North of Aljazeera State	50.41
North State	36.98
Other Countries (UNSCEAR 2000)	
Egypt	32
Algeria	70
Syrian Arab Republic	59
United States	47
Canada	63
Mexico	78
Indonesia	55
Hong Kong	87
Malaysia	92
Norway	73
France	68
Bulgaria	70
Greece	56
Portugal	84
Italy	74
Spain	76

Table (4.10): Areas of high natural radiation background (UNSCEAR 2000)

Country	Area	Absorbed dose rate in air (nGy. h^{-1})
	Guarapari	90 - 170 (streets) 90 - 90 000 (beaches) 110 - 1 300
	Mineas Gerais and Goias	340 average
	Pocos de Caldas Arax	2 800 average
China	Yangjiang Quangdong	 370 average
Egypt	Nile delta	20 – 400
France	Central region Southwest	20 – 400 10 - 10 000
India	Kerala and Madras Ganges delta	200-4 000 1 800 average 260 – 440
Iran	Ramsar Mahallat	70 - 17 000 800 - 4 000
Italy	Lazio Campania Orvieto town South Toscana	180 average 200 average 560 average 150 – 200
Niue Island	Pacific	1 100 maximum
Switzerland	Tessin, Alps, Jura	100 – 200

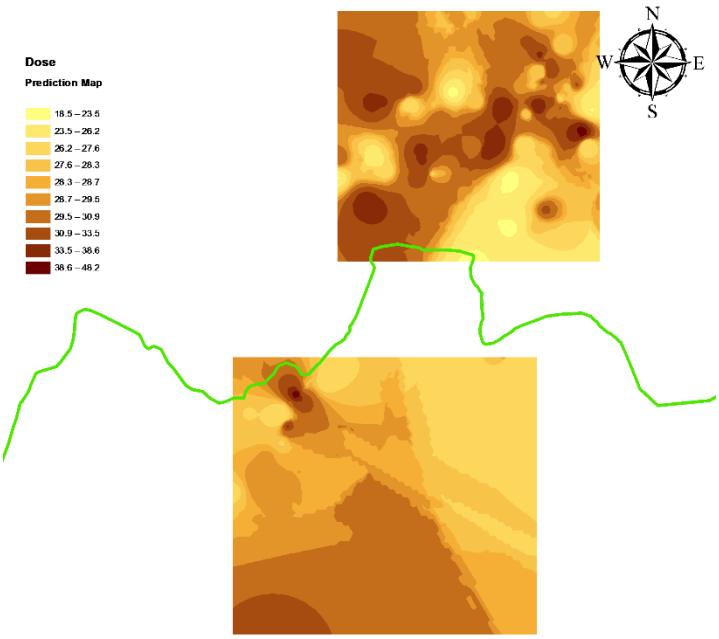


Figure (4.9): Predictive map for Absorbed Dose (displays values between 18.5 and 48.2)

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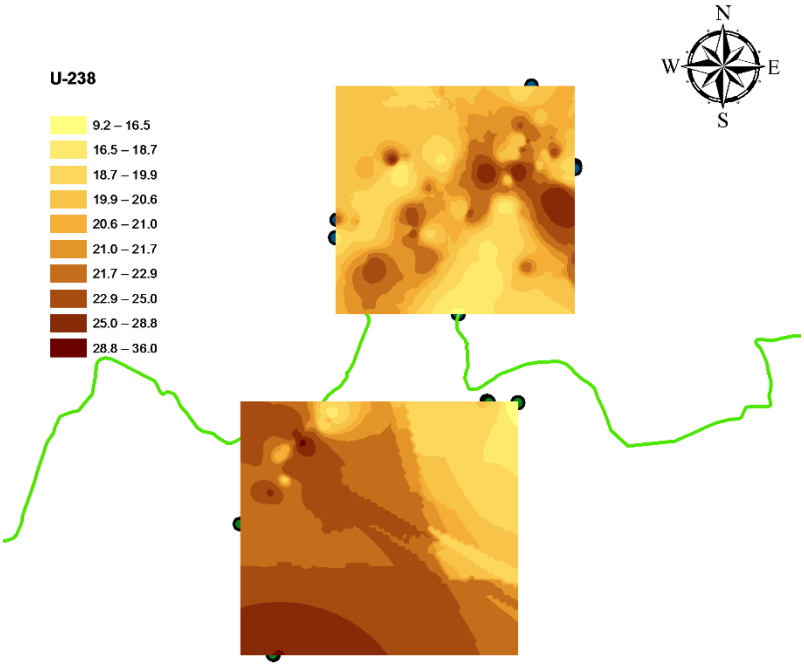


Figure (4.10): Predictive maps of ^{238}U

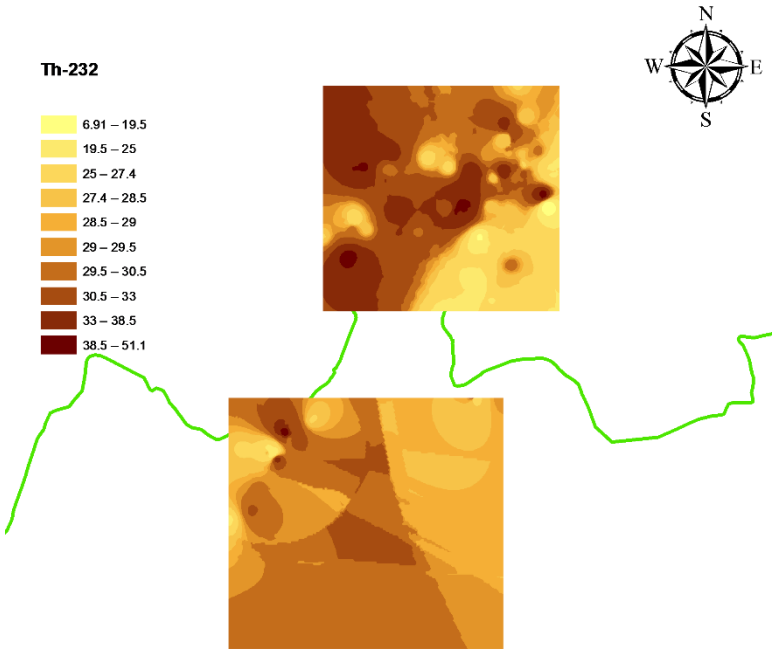


Figure (4.11): Predictive maps of ^{232}Th

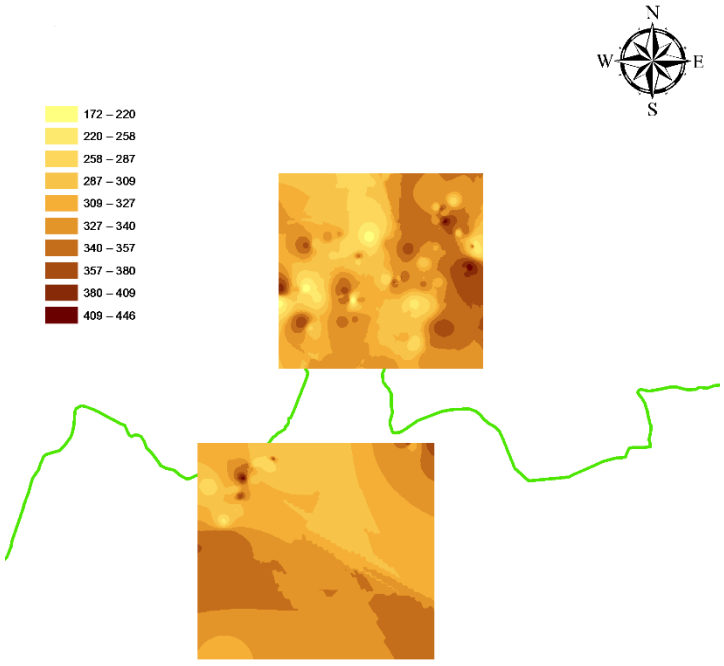


Figure (4.12): Predictive maps of ^{40}K

Table (4.11): Statistical summary of absorbed dose rate in air at 1 m height($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in North Kordofan using different DRCFs in Soil samples

DRCF	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
MC					
Mean ±Std	8.83±1.22	13.08±2.60	11.66±3.06	25.60±4.03	31.20±4.95
Range	7.33-10.26	9.99-16.45	7.11-15.01	20.87-30.59	25.68-37.55
Contribution %	34.49	51.09	45.55		
MCNP					
Mean ±Std	8.70±1.20	12.97±2.56	10.80±3.04	25.26±3.97	30.99±4.89
Range	7.21-10.19	9.86-16.23	7.09-14.57	20.59-30.2	25.25-37.06
Contribution %	34.44	51.35	42.76		
GEANT					
Mean ±Std	9.11±1.25	13.64±2.70	11.41±3.21	26.57±5.40	32.60±5.13
Range	7.57-14.17	10.38-17.08	7.5-15.4	21.51-31.76	26.58-38.99
Contribution %	34.29	51.34	42.94		
UNSCEAR					
Mean ±Std	10.55±1.46	15.15±3.74	11.9±3.36	29.61±4.64	41.72±6.71
Range	8.75-12.25	11.57-18.97	7.82-16.08	24.23-35.34	33.79-49.79
Contribution %	35.63	51.17	40.19		

Table (4.12): Statistical summary of absorbed dose rate in air at 1 m height($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in North Kordofan using different DRCFs in Soil samples

DRCF	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
MC						
Mean ±Std	4.76±0.79	0.87±0.18	6.87±1.37	11.66±3.06	5.22±2.67	24.01±4.34
Range	3.68-6.05	0.68-1.14	5.11-8.46	7.11-15.01	12.26-18.61	19.35-29.36
Contribution %	31.27	5.72	45.14	76.61		
MCNP						
Mean ±Std	0.44±0.09	0.82±0.17	6.81±1.36	10.80±3.04	10.77±2.05	17.00±3.23
Range	0.34-0.56	0.64-1.07	5.07-8.38	7.09-14.57	8.45-13.18	13.34-20.79
Contribution %	4.07	7.59	63.23	100.28		
GEANT						
Mean ±Std	0.47±.10	0.83±0.18	7.15±1.42		11.33±2.15	17.89±3.40
Range	0.37-0.59	0.67-1.12	5.32-8.8	11.41±3.21	8.9-13.87	14.04-21.88
Contribution %	4.15	7.33	63.31	7.5-15.4		
				100.71		
UNSCEAR						
Mean ±Std	14.92±3.00	8.53±1.88	9.18±1.87	11.9±3.36	36.31±6.26	57.29±9.93
Range	11.53-18.97	7.17-11.9	6.91-11.44	7.82-16.08	29.54-44.48	46.61-70.19
Contribution %	41.09	23.49	25.28	32.77		

Table (4.13): Statistical summary of absorbed dose rate in air at 1 m height($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in South Kordofan using different DRCFs in Soil samples

DRCF	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
MC					
Mean ±Std	8.8±1.59	15.74±2.34	12.15±2.16	26.08±4.03	37.16±4.61
Range	7.32-10.49	12.77-18	9.64-14.42	24.5-32.04	32.41-42.62
Contribution %	33.74	60.35	46.59		
MCNP					
Mean ±Std	8.67±1.56	14.98±1.40	11.95±1.95	28.05±2.48	34.42±3.04
Range	7.21-10.3	12.59-17.75	9.57-14.31	24.18-31.62	29.68-38.8
Contribution %	30.91	53.4	42.6		
GEANT					
Mean ±Std	8.65±1.56	15.68±3.68	12.75±2.27	32.88±4.04	38.53±4.80
Range	7.19-10.27	13.25-18.68	10.11-15.13	28.73-37.6	33.58-44.21
Contribution %	26.31	47.69	38.78		
UNSCEAR					
Mean ±Std	10.54±1.9	17.51±2.7	13.3±2.37	31±3.9	39.81±4.78
Range	5.92-10.37	15.06-18.87	8.59-16.46	26.78-33.78	32.86-41.47
Contribution %	34.00	56.48	42.90		

Table (4.14): Statistical summary of absorbed dose rate in air at 1 m height($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in South Kordofan using different DRCFs in Soil samples

DRCF	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
MC						
Mean ±Std	4.76±0.79	0.87±0.18	6.87±1.37	11.66±3.06	15.22±2.67	24.01±4.34
Range	3.68-6.05	0.68-1.14	5.11-8.46	7.11-15.01	12.26-18.61	19.35-29.36
Contribution %	31.27	5.72	45.14	76.61		
MCNP						
Mean ±Std	0.44±0.09	0.82±0.17	6.81±1.36	10.80±3.04	10.77±2.05	17.00±3.23

Range Contribution %	0.34-0.56 4.09	0.64-1.07 7.61	5.07-8.38 63.32	7.09-14.57 100.27	8.45-13.18	13.34-20.79
GEANT Mean ±Std Range Contribution %	0.47±.10 0.37-0.59 4.15	0.83±0.18 0.67-1.12 7.33	7.15±1.42 5.32-8.8 63.11	11.41±3.21 7.5-15.4 100.71	11.33±2.15 8.9-13.87	17.89±3.40 14.04-21.88
UNSCEAR Mean ±Std Range Contribution %	18.02±3.89 13.84-21.09 45.61	9.39±4.52 5.41-13.28 23.77	8.76±2.59 5.5-10.54 22.17	13.3±2.37 8.59-16.46	39.51±7.84 31.28-44.96	48.49±9.63 38.39-55.18

Table (4.15): Statistical summary of absorbed dose rate in air at 1 m height ($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U, ^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in Rocks samples using different DRCFs

DRCF	^{238}U	**^{232}Th**	**^{40}K**	nGy/h	µSv/y
MC Mean ±Std Range Contribution %	9.11±0.82 7.79-9.96 31.63	15.49±1.86 12.02-17.40 53.78	12.59±1.42 10.59-14.31 43.72	28.80±1.39 24.42-31.28	38.19±1.97 33.28-41.68
MCNP Mean ±Std Range Contribution %	8.97±0.81 7.68-9.81 31.56	15.28±2.24 11.86-17.17 53.76	12.49±1.40 10.51-14.21 43.95	28.42±2.88 24.11-30.87	34.88±3.53 29.58-37.89
GEANT Mean ±Std Range Contribution %	8.95±0.80 7.66-9.79 26.36	16.08±2.35 12.48-18.06 47.36	13.21±1.48 11.11-15.02 38.91	33.95±3.08 29.41-36.80	39.60±3.58 34.47-43.23
UNSCEAR Mean ±Std Range Contribution %	10.89±0.98 9.31-11.9 32.66	17.86±2.62 13.86-20.07 53.57	13.79±1.54 11.59-15.67 41.36	33.34±3.39 28.27-36.21	40.92±4.16 34.69-44.44

Table (4.16): Statistical summary of absorbed dose rate in air at 1 m height ($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in Rocks samples using different DRCFs

DRCF	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
MC						
Mean ±Std	0.56±0.07	0.93±0.14	6.86±1.15	12.59±1.42	11.50±1.41	14.11±1.73
Range	0.46-0.66	0.69-1.06	5.17-8.3	10.59-14.31	9.44-13.23	11.59-16.24
Contribution%	4.87	8.09	59.65	109.48		
MCNP						
Mean ±Std	0.52±0.07	0.87±0.13	6.80±1.14	12.49±1.40	11.32±1.39	13.89±1.70
Range	0.43-0.62	0.65-1	5.13-8.22	10.51-14.21	9.29-13.02	11.4-15.98
Contribution%	4.59	7.69	59.13	108.61		
GEANT						
Mean ±Std	0.56±0.07	0.93±0.14	6.86±1.15	13.21±1.48	11.65±1.42	25.94±2.72
Range	0.46-0.66	0.69-1.06	5.17-8.3	11.11-15.02	9.59-13.39	21.94-29.36
Contribution%	4.48	7.98	58.88	113.39		
UNSCEAR						
Mean ±Std	17.56±2.3	9.72±1.48	9.28±1.56	13.79±1.54	40.01`±4.49	49.10±5.51
Range	8	7.25-11.13	7-11.22	11.59-15.67	33.3-45.63	40.87-56
Contribution%	14.47-20.7	24.29	23.19	34.47		
	43.89					

Table (4.17): Statistical summary of absorbed dose rate in air at 1 m height (nGy/h) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (µSv/y) in foodstuff samples using different DRCFs

DRCF	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
MC					
Mean ±Std	1.75±0.34	2.35±0.73	12.42±4.97	5.53±1.79	7.89±2.76
Range	1.42-2.21	1.36-3.09	7.29-18.17	3.65-7.6	5.02-11.13
Contribution %	25.68	44.93	224.59		
MCNP					
Mean ±Std	1.78±0.33	2.32±0.72	12.34±4.93	5.48±1.78	6.72±2.18
Range	1.4-2.18	1.34-3.05	7.23-18.04	3.62-7.54	4.44-9.25
Contribution %	32.48	42.34	225.18		

GEANT Mean ±Std Range Contribution %	 1.87±0.44 1.53-2.25 30.6	 0.09±0.02 0.07-0.11 1.8	 13.03±5.21 8.49-20.29 1303	 5.00±1.73 3.5-7.4	 6.13±2.13 4.29-9.08
UNSCEAR Mean ±Std Range Contribution %	 2.16±0.40 1.7-2.65 35.06	 2.71±0.84 1.56-3.57 43.99	 14.30±5.43 7.98-19.9 232.14	 6.16±1.98 4.08-8.45	 7.56±2.43 5.01-10.37

Table (4.18): Statistical summary of absorbed dose rate in air at 1 m height($nGyh^{-1}$) (mean and range) due to γ-emitters from ^{238}U ,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective dose (μSvy^{-1}) in foodstuff samples using different DRCFs

DRCF	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
MC Mean ±Std Range Contribution%	 0.09±0.03 0.05-0.11 2.47	 0.17±0.06 0.1-0.25 4.66	 1.91±0.37 1.38-2.34 52.33	 12.42±4.97 7.29-18.17 340.27	 3.65±1.19 2.43-5	 4.48±1..46 2.99-6.13
MCNP Mean ±Std Range Contribution%	 0.08±0.03 0.05-0.11 2.21	 0.16±0.06 0.09-0.24 4.42	 1.89±0.37 1.37-2.32 52.21	 12.34±4.93 7.23-18.04 340.88	 3.62±1.18 2.41-4.96	 4.44±1.45 2.96-6.08
GEANT Mean ±Std Range Contribution%	 0.09±0.10 0.05-0.11 2.36	 0.16±0.06 0.1-0.25 4.19	 1.99±3.82 1.44-2.44 52.09	 13.03±5.21 8.49-20.29 341.1	 3.82±1.25 2.54-5.24	 4.69±1.53 3.12-6.43
UNSCEAR Mean ±Std Range Contribution%	 2.71±0.84 1.56-3.57 52.52	 1.73±0.69 1.03-2.64 33.53	 2.58±0.50 1.87-3.16 0.5	 14.30±5.43 7.98-19.9 277.13	 5.16±1.53 3.55-6.9	 6.30±1.88 4.36-8.47

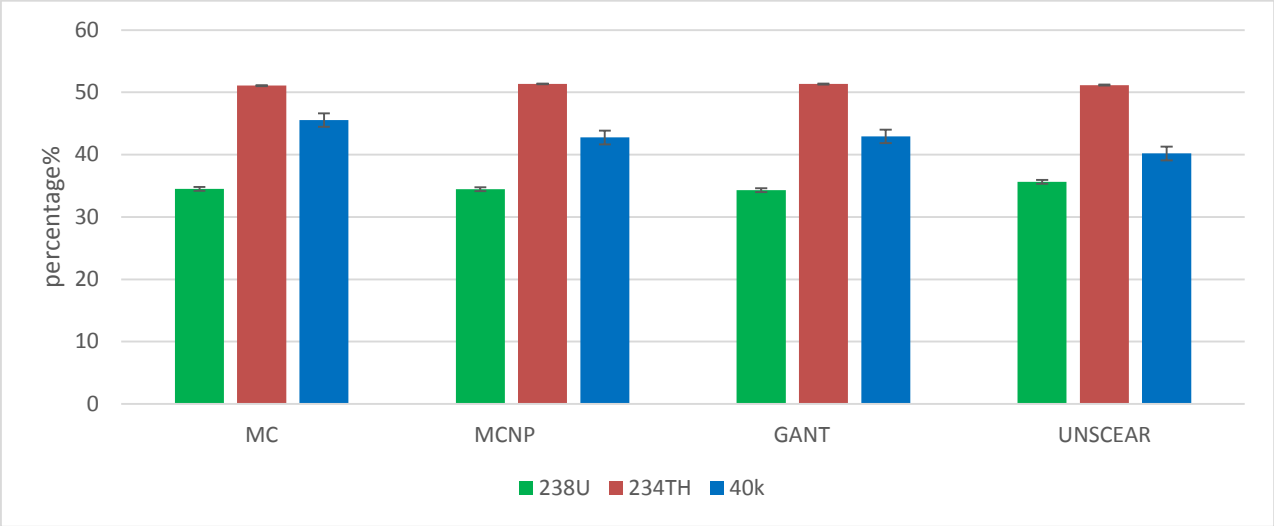


Figure (4.9): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in soil samples-North Kordofan

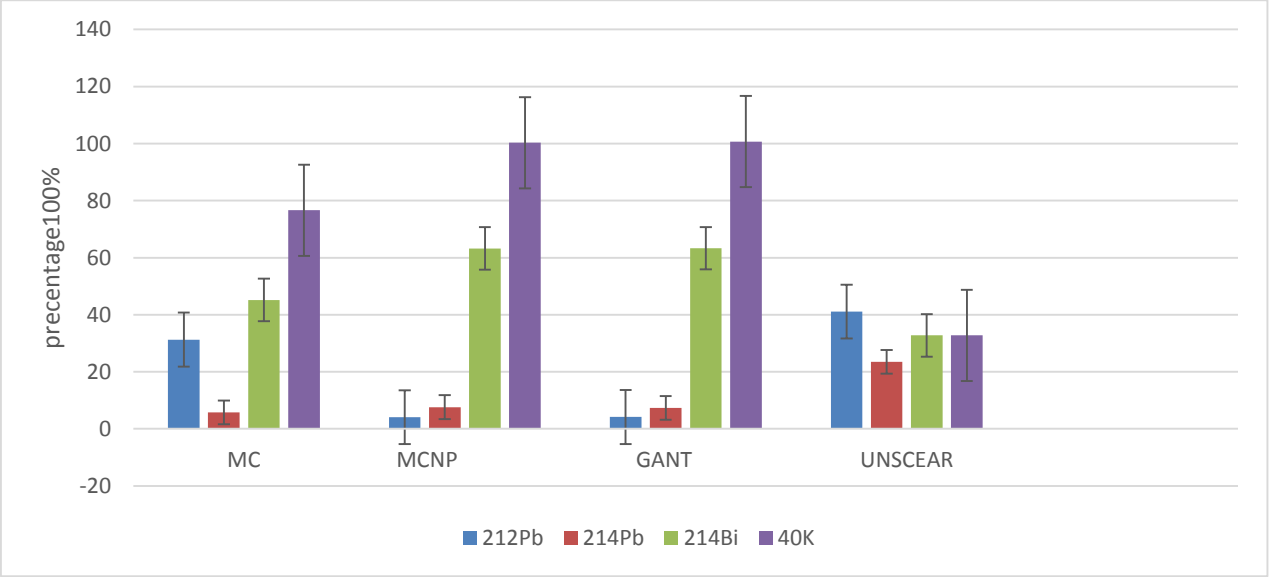


Figure (4.10): Relative contribution of ^{238}U, ^{232}Th series and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in Soil samples -North kordofan

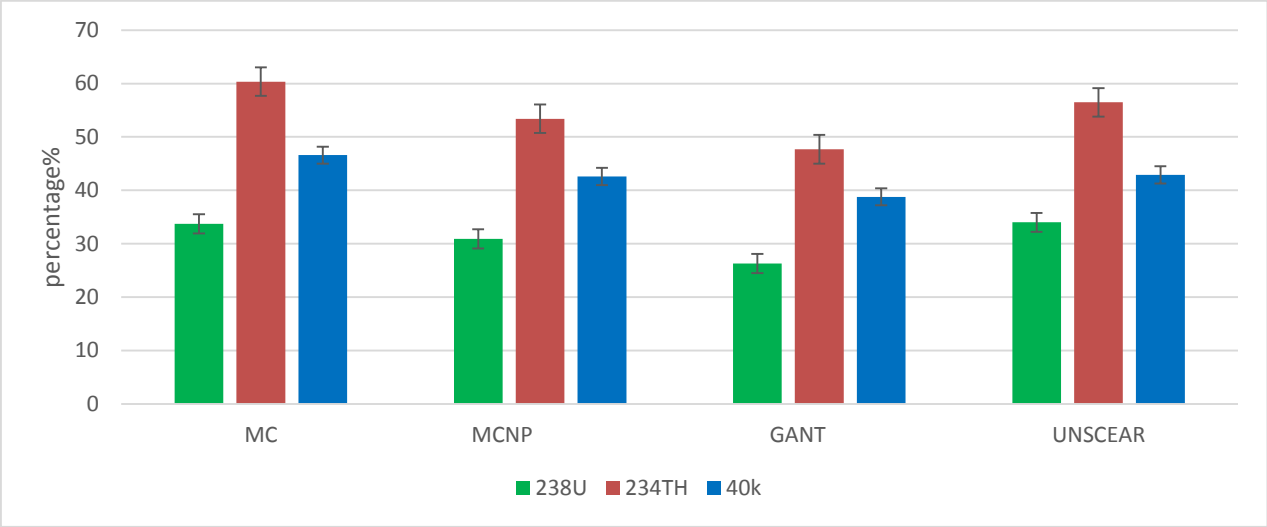
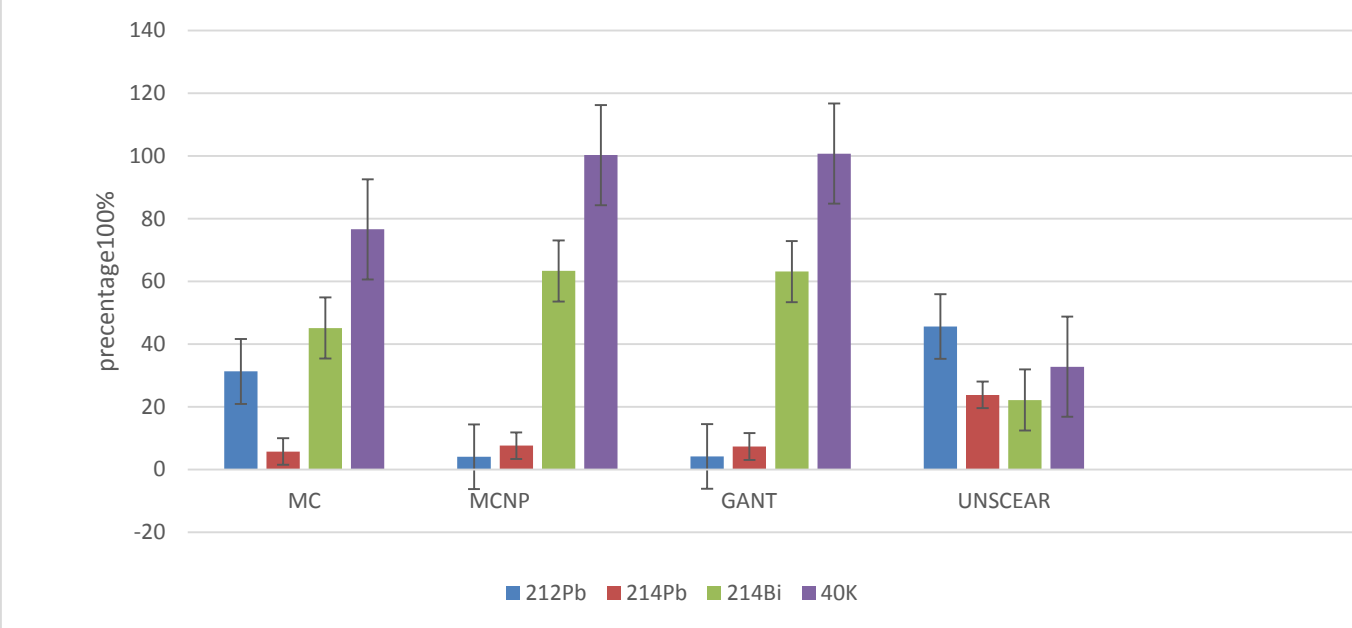


Figure (4.11): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in soil samples -South kordofan



Figre (4.12): Relative contribution of ^{238}U, ^{232}Th series and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in Soil samples -South Kordofan

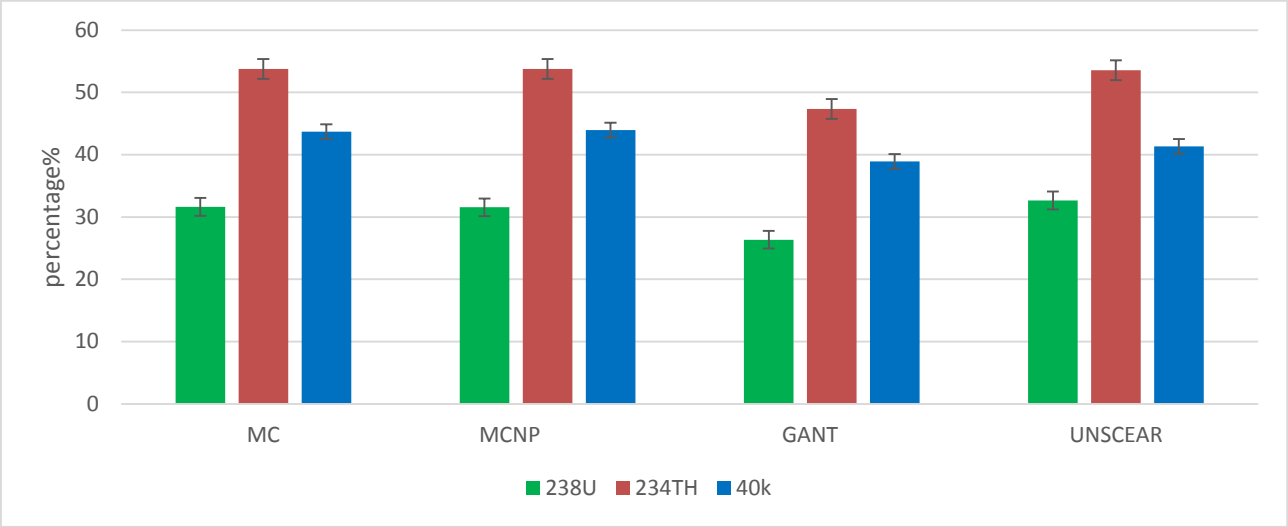


Figure (4.13): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in rock samples

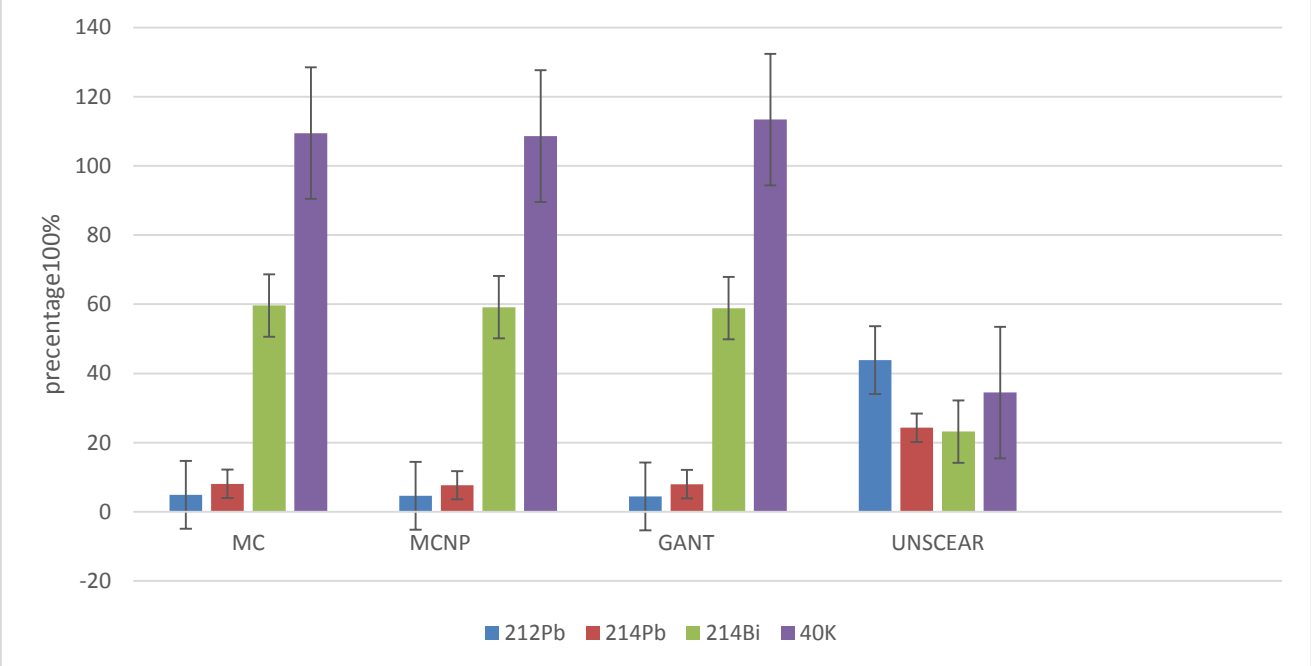


Figure (4.14): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in rock samples

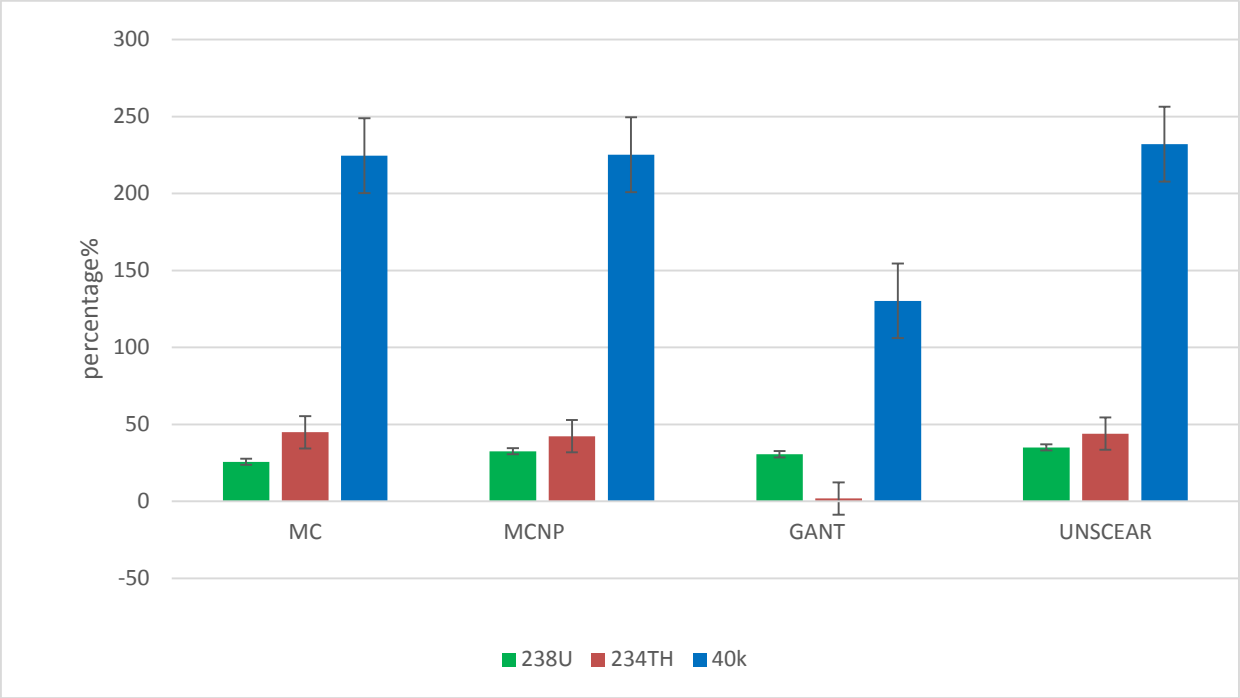


Figure (4.15): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in foodstuff samples

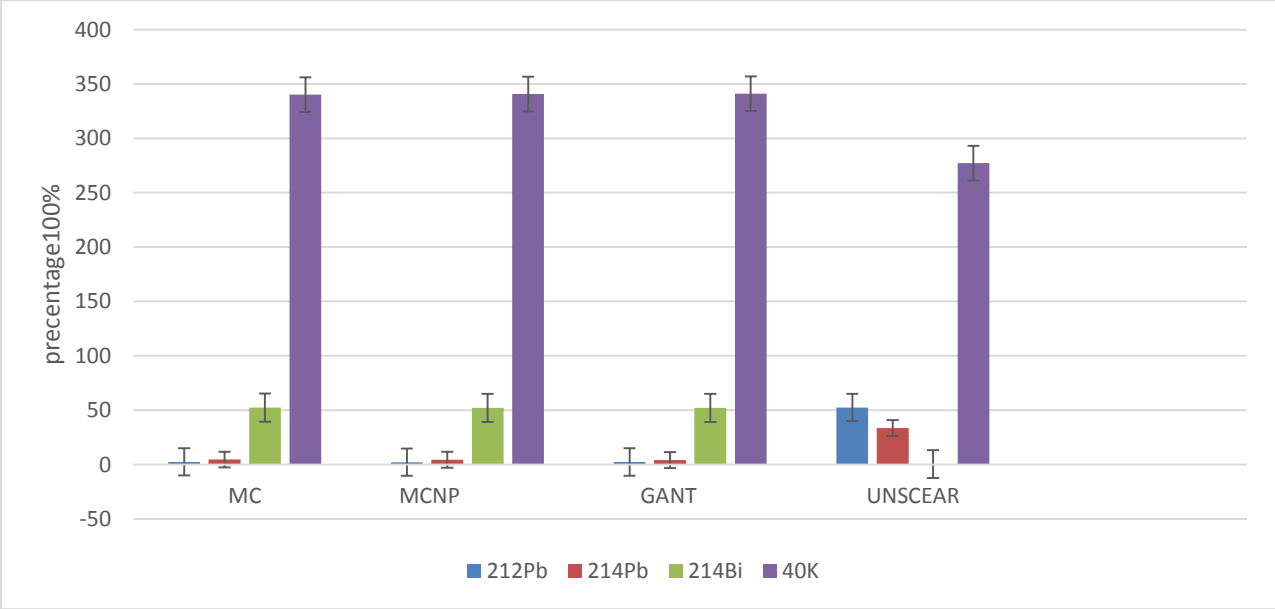


Figure (4.16): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCF in foodstuff

CONCLUSION

Based on calculations of absorbed dose rate in air at one meter above ground surface attributable to gamma-emitters from ^{238}U, ^{232}Th series, and ^{40}K using different sets of dose rate conversion factors (DRCFs) and the annual effective dose, one can conclude the following:

i. There is non-uniformity in geological features as inferred from high spatial variability in activity concentration of ^{238}U, ^{232}Th series, and ^{40}K in all areas under investigation are within the world wide values reported by UNSCEAR (2000).

ii. Upon comparing the calculated absorbed dose rate in air and the corresponding annual effective dose with similar data from different regions in Sudan, world-wide and from well recognized high natural radiation background areas, North and south Kordofan state falls within the category of lowest radiation background areas in the world.

iv. The four sets of DRCFs used for estimation of absorbed dose rate have shown unremarkable variation.

v. Further studies are needed to achieve the goal of establishing a radiation map for North and south Kordofan state.

Appendix

Table (1): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	**Number of sample**	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Hashaba	2	8.21±0.94	11.06±0.90	11.93±1.62	23.25±2.38	28.53±2.93
Kazail	8	9.23±1.27	13.56±1.77	11.76±1.36	26.72±3.23	32.79±3.96
Banjadid	3	11.52±2.12	16.1±3.10	22.33±1.32	31.39±4.93	38.54±6.05
Jable kofdofan	3	10.96±2.03	11.42±9.70	17.10±5.59	28.07±12.13	34.45±14.88
ElObied	12	8.29±1.26	11.88±3.25	8.66±2.55	23.05±4.74	28.29±5.81
Khortaget	9	8.57±0.49	12.48±1.17	12.96±4.99	25.37±2.62	31.14±3.22
Mosfa elobied	10	7.00±1.20	9.68±2.18	9.35±2.43	19.80±2.51	24.29±3.07
El eyarh	7	9.02±1.14	16.04±4.83	10.78±3.13	28.63±5.80	32.13±7.12
Abou haraz	13	8.86±1.24	15.10±2.18	10.16±3.55	27.35±3.86	33.57±4.73
Anumair	3	8.07±1.18	11.06±1.89	8.93±6.71	22.10±5.17	27.13±6.34
Wad mkashvi	2	7.94±1.32	11.91±0.60	7.52±4.16	22.36±3.30	27.44±4.05
Om bauid	7	7.32±1.72	12.12±0.61	9.34±1.16	23.40±1.96	28.72±2.41
Elgaka	3	8.92±0.23	14.11±0.68	10.78±1.70	26.62±0.38	32.67±0.47
Hilla sad	3	9.67±0.87	16.66±3.51	11.66±2.62	30.22±3.45	37.08±4.24
Total Averge ±SD	85	8.83±1.22	13.08±2.60	11.66±3.06	25.60±4.03	31.20±4.95
Min		7.33	9.99	7.11	20.87	25.68
Max		10.26	16.45	15.01	30.59	37.55

Table (2): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	**Number of sample**	**^{238}U**	**$^{23}2Th$**	**^{40}K**	**nGy/h**	**µSv/y**
Hashaba	2	8.09±0.93	10.91±0.89	11.84±1.61	22.95±2.35	28.16±2.89
Kazail	8	9.10±1.25	13.38±1.74	11.68±1.35	26.37±3.18	32.36±3.91
Banjadid	3	11.35±2.09	15.88±3.06	11.24±1.31	30.97±4.86	38.01±5.96
Jable kofdofan	3	10.79±1.99	11.26±9.57	16.98±5.55	27.71±11.97	34.01±14.69
ElObied	12	8.17±1.24	11.72±3.21	8.60±2.53	22.75±4.68	27.92±5.74
Khortaget	9	8.45±0.48	12.31±1.16	12.87±4.96	25.04±2.60	30.74±3.18
Mosfa elobied	10	6.90±1.18	9.55±2.15	9.28±2.41	19.54±2.28	23.98±3.04
El eyarh	7	8.88±1.13	15.80±4.77	10.7±3.11	28.25±5.73	34.67±7.03
Abou haraz	13	8.73±1.21	14.90±2.15	10.08±3.52	26.99±3.81	33.12±4.67
Anumair	3	7.94±1.17	10.91±1.87	8.87±6.66	21.81±5.11	26.77±6.27
Wad mkashvi	2	7.82±1.30	11.75±0.59	7.46±4.12	22.06±3.27	27.07±4.01
Om bauid	7	7.21±1.69	12.80±0.61	9.27±1.15	23.1±1.92	28.34±2.38
Elgaka	3	8.79±0.23	13.92±0.67	10.70±1.69	26.27±0.37	32.24±0.46
Hilla sad	3	9.52±0.86	16.44±3.46	11.56±2.60	29.82±3.41	36.59±4.19
Averge ±SD	85	8.70±1.20	12.97±2.56	10.80±3.04	25.26±3.97	30.99±4.89
Min		7.21	9.86	7.09	20.59	25.25
Max		10.19	16.23	14.57	30.2	37.06

(3): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using GEANT DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Hashaba	2	8.39±0.97	11.48±0.94	12.51±1.70	24.14±2.48	29.62±3.04
Kazail	8	9.54±1.31	14.07±1.83	12.34±1.43	27.73±3.35	34.03±4.11
Banjadid	3	11.90±2.19	16.70±3.22	11.88±1.39	32.57±5.10	39.97±6.26
Jable kofdofan	3	11.32±2.09	11.85±10.07	17.94±5.86	29.15±12.60	35.78±15.37
ElObied	12	8.57±1.30	12.33±3.37	9.09±2.67	23.92±4.92	29.36±6.03
Khortaget	9	8.86±0.50	12.95±1.22	13.60±5.24	26.34±2.74	32.33±3.36
Mosfa elobied	10	7.23±1.23	10.04±2.27	9.81±2.55	20.55±2.61	25.22±3.20
El eyarh	7	9.32±1.18	16.62±5.01	11.31±3.28	29.71±6.02	36.46±7.39
Abou haraz	13	9.16±1.28	15.67±2.26	10.65±3.72	28.39±4.01	34.84±4.92
Anumair	3	8.33±1.22	11.48±1.96	9.37±7.04	22.94±5.38	28.15±6.60
Wad mkashvi	2	8.21±1.36	12.36±0.62	7.89±4.36	23.20±3.44	28.47±4.22
Om bauid	7	7.56±1.77	13.47±0.64	9.80±1.21	24.29±2.03	29.81±2.49
Elgaka	3	9.22±0.24	14.64±0.71	11.31±1.78	27.63±0.39	33.91±0.48
Hilla sad	3	9.99±0.90	17.29±3.64	12.23±2.75	31.36±3.59	38.49±4.41
Averge ±SD	85	9.11±1.25	13.64±2.70	11.41±3.21	26.57±5.40	32.60±5.13
Min		7.57	10.38	7.5	21.5	26.58
Max		14.17	17.08	15.4	31.8	38.99

Table (4): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in soil samples (North kordofan)

Location	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Hashaba	2	9.8±1.23	12.75±1.04	13.06±1.77	26.92±2.76	37.51±3.75
Kazail	8	11.03±1.52	15.63±2.4	12.88±1.49	30.96±3.76	43.48±5.31
Banjadid	3	13.76±2.53	18.56±3.57	12.41±1.45	36.46±5.79	51.25±8.35
Jable kofdofan	3	13.09±2.42	13.16±11.19	18.73±6.12	32.49±13.92	44.49±20.91
ElObied	12	9.90±1.50	13.69±3.75	9.48±2.79	26.76±5.48	37.64±8.00

Khortaget	9	10.24±0.58	14.39±1.35	14.19±5.47	29.36±2.95	41.08±4.01
Mosfa elobied	10	8.37±1.43	11.16±2.52	10.23±2.66	22.94±2.84	32.06±4.31
El eyarh	7	10.77±1.36	18.46±5.57	11.81±3.43	33.17±6.71	47.18±10.10
Abou haraz	13	10.59±1.48	17.41±2.52	11.12±3.89	31.71±4.43	45.02±6.24
Anumair	3	9.64±1.42	12.75±2.18	9.78±7.35	25.65±5.88	35.95±7.96
Wad mkashvi	2	9.49±1.57	13.73±0.69	8.23±4.55	25.96±3.78	36.68±4.89
Om bauid	7	8.74±2.05	14.96±0.71	10.22±1.27	27.11±2.35	38.51±3.08
Elgaka	3	10.66±0.27	16.26±0.79	11.81±1.86	30.01±0.47	43.58±0.84
Hilla sad	3	11.55±1.04	19.21±4.04	12.76±2.87	35.02±3.93	49.71±6.24
Total Averge ±SD		10.55±1.46	15.15±3.74	11.9±3.36	29.61±4.64	41.72±6.71
Min		8.75	11.57	7.82	24.2	33.79
Max	85	12.25	18.97	16.08	35.3	49.97

Table (5): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan).

location	**Number of sample**	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Kazqil	2	11.01±3.06	15.74±2.23	12.25±1.62	30.83±1.38	38.86±0.51
Tayba	2	8.61±1.78	15.74±0.67	11.27±0.69	28.11±2.68	36.67±2.40
Showshaya	3	8.33±1.06	12.69±8.03	12.20±2.32	9.39±14.86	33.96±12.73
Krkraah	2	8.33±1.17	13.93±0.11	11.27±2.08	26.02±0.59	34.34±1.94
Dubaibat	5	8.31±1.05	15.89±1.08	11.83±3.98	28.15±3.18	37.42±6.25
Dalanj	8	9.78±1.87	16.54±4.35	12.58±2.15	30.52±4.97	39.74±5.89
Al Hamadi	3	8.94±1.08	16.21±0.96	13.18±1.68	29.54±2.36	39.73±3.46
El Dilema	6	7.11±1.61	14.77±1.27	12.64±2.79	26.09±2.24	36.54±3.72
Total Averge ±SD		8.8±1.59	15.74±2.34	12.15±2.16	26.08±4.03	37.16±4.61
Min		7.32	12.77	9.64	24.5	32.41
Max	31	10.46	18	14.42	32.04	42.62

Table (6): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan)

location	**Number of sample**	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Kazqil	2	10.85±3.02	15.52±2.20	12.16±1.61	30.43±1.36	37.34±1.66
Tayba	2	8.48±1.75	15.52±0.66	11.19±0.69	27.74±2.64	34.04±3.24
Showshaya	3	8.20±1.04	12.52±0.66	11.19±0.69	27.74±2.64	34.04±3.24
Krkraah	2	8.21±1.15	13.74±0.11	11.19±2.06	25.68±0.57	31.51±0.70
Dubaibat	5	8.19±1.04	15.68±1.07	11.74±3.96	27.78±3.14	34.10±3.85
Dalanj	8	9.63±1.85	16.32±4.29	12.49±2.14	30.11±4.91	36.96±6.02
Al Hamadi	3	8.81±1.07	15.99±0.94	13.08±1.66	29.16±2.33	35.78±2.86
El Dilema	6	7.01±1.59	14.57±1.25	12.54±2.77	25.75±2.21	31.60±2.71
Total Averge±SD	31	8.67±1.56	14.98±1.40	11.95±1.95	28.05±2.48	34.42±3.04
Min		7.21	12.59	9.57	24.18	29.68
Max		10.3	17.75	14.31	31.62	38.8

Table (7): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in soil samples (South kordofan)

location	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Kazqil	2	10.82±3.01	16.33±2.31	12.86±1.70	34.60±0.89	40.25±0.48
Tayba	2	8.46±1.75	16.33±0.69	11.83±0.73	32.39±2.29	38.02±2.46
Showshaya	3	8.18±1.04	13.17±8.33	12.80±2.43	30.38±10.90	35.22±13.23
Krkraah	2	8.19±1.15	14.45±0.12	11.83±2.18	30.38±1.49	35.60±2.07
Dubaibat	5	8.17±1.04	16.49±1.13	12.41±4.18	32.99±5.45	38.82±6.52
Dalanj	8	9.61±1.84	17.17±4.52	13.20±2.26	35.17±5.04	41.20±6.12
Al Hamadi	3	8.79±1.06	16.17±0.99	13.83±1.76	35.04±3.05	41.21±3.60
El Dilema	6	6.99±1.59	15.32±1.32	13.26±2.93	32.07±3.17	37.93±3.89
Total Averge ±SD	31	8.65±1.56	15.68±3.68	12.75±2.27	32.88±4.04	38.53±4.80
Min		7.19	13.25	10.11	28.73	33.58
Max		10.27	18.68	15.13	37.6	44.21

Table (8): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan)

location	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Kazqil	2	13.36±3.66	18.14±2.57	13.42±1.77	35.77±1.68	43.90±2.07
Tayba	2	10.29±2.13	18.14±0.77	12.25±0.76	32.55±3.15	39.64±3.86
Showshaya	3	9.95±1.26	14.64±9.26	13.36±2.54	29.04±10.82	35.64±13.27
Krkraah	2	9.96±1.40	16.06±0.13	12.35±2.28	30.13±0.77	36.97±0.94
Dubaibat	5	9.93±1.26	18.32±1.25	12.95±4.36	32.58±3.64	39.98±4.46
Dalanj	8	11.68±2.24	19.07±5.02	13.78±2.36	35.35±5.78	43.38±7.09

Al Hamadi	3	10.68±1.29	18.69±1.10	14.43±1.84	34.18±2.73	41.95±3.35
El Dilema	6	8.50±1.93	17.02±1.46	13.84±3.06	30.13±2.62	36.98±3.21
Total Averge ±SD		10.54±1.9	17.51±2.7	13.3±2.37	31±3.9	39.81±4.78
Min		5.92	15.06	8.59	26.78	32.86
MaX	31	10.37	18.87	16.46	33.78	41.47

Table (9): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in Rocks samples.

Location	**Number of sample**	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Jable kordofan	11	9.01±1.23	15.46±1.46	11.94±1.49	28.46±2.63	37.32±3.03
Jable Bala	4	9.64±0.28	17.00±0.84	12.83±1.32	30.91±0.89	40.54±1.78
Jable Kogoer	4	8.20±1.22	12.63±5.71	12.58±1.95	25.02±0.81	34.29±0.85
Jable Belengokaa	5	9.23±0.60	16.43±0.87	12.61±0.75	29.87±1.20	39.42±1.74
Jabl Dash	7	9.47±0.75	15.94±0.42	12.98±1.58	29.74±1.44	39.36±2.43
Total Averge ±SD		9.11±0.82	15.49±1.86	12.59±1.42	28.80±1.39	38.19±1.97
Min		7.79	12.02	10.59	24.42	33.28
Max	31	9.96	17.40	14.31	31.28	41.68

Table (10): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in Rock samples

location	Number of Sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Jable kordofan	11	8.88 ±1.22	15.25±1.44	11`.85±1.48	28.09±2.60	34.47 ±3.19
Jable Bala	4	9.49 ±0.28	16.76±0.83	12.73±1.31	30.50±0.88	37.43 ±1.08
Jable Kogoer	4	8.08 ±1.20	12.46±7.63	12.49±1.94	24.70±8.31	30.31±10.19
Jable Belengokaa	5	9.09 ±0.59	16.21±0.86	12.52±0.75	29.47±1.19	36.17±1.45
Jabl Dash	7	9.33 ±0.74	15.72±0.42	12.88±1.53	29.35±1.42	36.02±1.74
Averge ±SD		8.97±0.81	15.28±2.24	12.49±1.40	28.42±2.88	34.88±3.53
Min		7.68	11.86	10.51	24.11	29.58
Max	31	9.81	17.17	14.21	30.87	37.89

Table (11): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in Rocks samples

Location	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Jable Kordofan	11	8.86±1.21	16.05±1.52	12.53±1.57	33.0`1±2.74	38.70±3.14
Jable Bala	4	9.47±0.28	17.64±0.87	13.46±1.38	35.83±1.51	42.03±1.86
Jable Kogoer	4	8.06±1.20	13.11±8.03	13.20±2.05	30.34±7.16	35.58±8.55
Jable Belengokaa	5	9.07±0.59	17.05±0.91	13.23±0.79	34.82±1.50	40.88±1.81
Jabl Dash	7	9.31±0.74	16.54±0.44	13.62±1.62	34.81±2.15	40.82±2.53
Averge ±SD		8.95±0.80	16.08±2.35	13.21±1.48	33.95±3.08	39.60±3.58
Min		7.66	12.48	11.11	29.41	34.47
Max	31	9.79	18.06	15.02	36.80	43.23

Table (12): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in Rocks samples

location	**Number of sample**	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Jable kordofan	11	10.77±1.47	17.83±1.69	13.08±1.63	32.96±3.07	40.45±3.77
Jable Bala	4	11.51±0.34	19.59±0.97	14.05±1.44	35.79±1.02	43.92±1.26
Jable Kogoer	4	9.80±1.46	14.56±8.92	13.78±2.14	28.95±9.79	35.53±12.01
Jable Belengokaa	5	11.03±0.72	18.94±1.01	13.81±0.82	34.58±1.39	42.43±1.71
Jabl Dash	7	11.32±0.89	18.38±0.49	14.21±1.69	34.43±1.66	42.26±2.04
Total Averge ±SD		10.89±0.98	17.86±2.62	13.79±1.54	33.34±3.39	40.92±4.16
Min		9.31	13.86	11.59	28.27	34.69
Max	31	11.9	20.07	15.67	36.21	44.44

Table (13): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in food stuff samples

Type of food	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Maize	5	1.78±0.16	2.50±1.50	20.18±6.42	8.16±2.27	12.00±3.49
Cordia africana	*5*	1.50±0.37	2.04±1.02	12.12±6.12	5.24±2.32	7.56±3.62
Portulaca	5	1.37±0.36	2.46±0.50	11.49±4.43	5.23±1.56	7.45±2.52
Okra	5	2.09±0.44	2.59±0.54	13.29±6.26	5.99±2.40	8.49±3.57
Molokhia	5	1.75±0.22	2.38±0.28	11.27±5.95	5.13±2.07	7.29±3.20
Peanuts	4	1.99±0.47	2.14±0.52	6.17±0.61	3.43±0.14	4.54±0.14
Total Averg**±SD**	29	1.75±0.34	2.35±0.73	12.42±4.97	5.53±1.79	7.89±2.76
MIN		1.42	1.36	7.29	3.65	5.02
MAX		2.21	3.09	18.17	7.6	11.13

Table (14): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in food stuff samples.

Type of food	Number of sample	**^{238}U**	**^{232}Th**	**^{40}K**	**nGy/h**	**µSv/y**
Maize	5	1.76±0.16	2.47±1.48	20.03±6.37	8.09±2.25	9.92±2.76
Cordia africana	*5*	1.47±0.36	2.02±1.00	12.08±6.07	5.19±2.30	6.37±2.83
Portulaca	5	1.70±0.36	2.43±0.49	11.41±4.40	5.18±1.55	6.36±1.90
Okra	5	2.06±0.43	2.55±0.54	13.19±6.21	5.93±2.38	7.28±2.92
Molokhia	5	1.72±0.22	2.35±0.28	11.19±5.90	5.08±2.06	6.24±2.52
Peanuts	4	1.96±0.46	2.11±0.51	6.12±0.60	3.40±0.14	4.17±0.17
Averge ±SD	29	1.78±0.33	2.32±0.72	12.34±4.93	5.48±1.78	6.72±2.18
MIN		1.4	1.34	7.23	3.62	4.44
MAX		2.18	3.05	18.04	7.54	9.25

Table (15): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in food stuff samples

Type of food	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Maize	5	1.84±0.7	0.09±0.01	21.12±6.74	7.70±2.28	9.45±2.80
Cordia africana	*5*	1.55±0.38	0.07±0.02	12.76±6.42	4.79±2.14	5.88±2.63
Portulaca	5	1.79±0.38	0.09±0.02	12.06±4.65	4.64±1.47	5.70±1.80
Okra	5	2.16±0.46	0.10±0.02	13.94±6.56	5.40±2.34	6.63±2.87
Molokhia	5	1.81±0.23	0.09±0.01	11.82±6.24	4.57±2.11	5.61±2.59
Peanuts	4	2.05±0.49	0.10±0.02	6.47±0.64	2.87±0.06	3.53±0.07
Total Averge ±SD	29	1.87±0.44	0.09±0.02	13.03±5.21	5.00±1.73	6.13±2.13
MIN		1.53	0.07	8.49	3.5	4.29
MAX		2.25	0.11	20.29	7.4	9.08

Table (16): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in foodstuffs samples

Type of food	Number of sample	^{238}U	^{232}Th	^{40}K	nGy/h	µSv/y
Maize	5	2.13±0.19	2.89±1.73	22.10±7.03	9.04±2.49	11.09±3.06
Cordia africana	*5*	1.79±0.44	2.36±1.17	13.32±6.70	5.82±2.56	7.15±3.14
Portulaca	5	2.06±0.43	2.84±0.57	12.59±4.85	5.83±1.71	7.15±2.10
Okra	5	2.50±0.53	2.98±0.63	14.55±6.85	6.68±2.65	8.19±3.25
Molokhia	5	2.09±0.27	2.74±0.32	12.34±6.51	5.72±2.28	7.02±2.79
Peanuts	4	2.37±0.56	2.47±0.60	6.75±0.66	3.86±0.18	4.74±0.22
Total Averge±SD	29	2.16±0.40	2.71±0.84	14.30±5.43	6.16±1.98	7.56±2.43
MIN		1.7	1.56	7.98	4.08	5.01
MAX		2.65	3.57	19.9	8.45	10.37

Table (17): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclide from ^{238}U, ^{232}Th series and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Hashaba	2	4.07±0.33	0.76±0.11	6.53±0.99	11.93±1.62	14.33±1.84	22.61±2.90
Kazail	8	4.99±0.65	0.91±0.16	7.46±1.24	11.76±1.36	16.29±1.94	25.71±3.06
Banjadid	3	5.92±1.4	1.27±0.46	9.63±2.57	22.33±1.32	19.65±3.93	31.01±6.20
Jable kofdofan	3	4.20±3.57	1.27±0.27	9.17±2.04	17.10±5.59	18.91±6.75	29.84±10.64
ElObied	12	4.37±1.19	0.74±0.15	5.79±1.41	8.66±2.55	13.06±1.81	20.61±4.65
Khortaget	9	4.59±0.43	0.87±0.04	6.42±0.45	12.96±4.99	15.12±1.81	23.85±2.86
Mosfa elobied	10	3.56±0.80	0.80±0.41	5.24±0.76	9.35±2.43	11.94±0.86	18.84±1.36
El eyarh	7	5.89±1.78	0.79±0.16	7.29±1.64	10.78±3.13	16.67±3.62	26.30±5.71
Abou haraz	13	4.50±0.80	0.84±0.16	6.35±1.75	10.16±3.55	14.26±2.69	22.51±4.24

Anumair	3	4.07±0.70	0.70±0.09	5.36±1.30	8.93±6.71	12.36±3.67	19.51±5.79
Wad mkashvi	2	4.38±0.22	0.73±0.07	6.06±1.32	7.52±4.16	13.05±2.65	20.59±4.19
Om bauid	7	4.77±0.23	0.65±0.24	5.13±2.18	9.34±1.16	12.89±2.41	20.34±3.80
Elgaka	3	5.18±0.25	0.83±0.03	6.99±0.70	10.78±1.70	15..71±0.74	24.79±1.17
Hilla sad	3	6.13±1.29	1.06±0.17	8.70±0.82	11.66±2.62	18.80±2.62	29..67±4.14
Total Averge ±SD		4.76±0.79	0.87±0.18	6.87±1.37	11.66±3.06	15.22±2.67	24.01±4.34
Min		3.68	0.68	5.11	7.11	12.26	19.35
Max		6.05	1.14	8.46	15.01	18.61	29.36

Table (18): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	**N.of sample**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
Hashaba	2	0.38±0.03	0.71±0.10	6.47±0.98	11.84±1.61	10.52±1.52	16.60±2.39
Kazail	8	0.46±0.06	0.85±0.15	7.39±1.23	11.68±1.35	11.63±1.48	18.35±2.33
Banjadid	3	0.55±0.11	1.19±0.43	9.55±2.54	11.24±1.31	14.10±2.85	22.25±4.50
Jable kofdofan	3	0.39±0.33	1.19±0.25	9.09±2.02	16.98±5.55	14.91±3.84	23.53±6.06
ElObied	12	0.41±0.11	0.70±0.15	5.74±1.40	8.60±2.53	8.99±1.92	14.19±3.03
Khortaget	9	0.43±0.04	0.81±0.04	6.37±0.45	12.87±4.96	10.82±1.63	17.08±2.58
Mosfa elobied	10	0.33±0.07	0.75±0.39	5.20±0.75	9.28±2.41	8.60±0.67	13.57±1.05
El eyarh	7	0.55±0.17	0.74±0.15	7.23±1.62	10.7±3.11	11.19±2.27	17.66±3.58
Abou haraz	13	0.42±0.07	0.79±0.15	6.29±1.73	10.08±3.52	10.06±2.28	15.88±3.60
Anumair	3	0.38±0.06	0.66±0.07	5.31±1.29	8.87±6.66	8.57±3.05	13.52±4.81
Wad mkashvi	2	0.41±0.02	0.69±0.07	6.01±1.31	7.46±4.12	8.97±2.43	14.15±3.83
Om bauid	7	0.44±0.02	0.62±0.22	5.08±2.16	9.27±1.15	8.46±2.24	13.35±3.54
Elgaka	3	0.48±0.02	0.78±0.02	6.93±0.69	10.70±1.69	10.87±0.78	17.16±1.23
Hilla sad	3	0.57±0.12	1.00±0.16	8.62±0.81	11.56±2.60	13.08±1.68	20.65±2.65
Tatol Averge±SD		0.44±0.09	0.82±0.17	6.81±1.36	10.80±3.04	10.77±2.05	17.00±3.23
Min		0.34	0.64	5.07	7.09	8.45	13.34
Max		0.56	1.07	8.38	14.57	13.18	20.79

Table (19): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan)

Location	**Number of sample**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
Hashaba	2	0.40±0.03	0.74±0.11	6.79±1.03	12.51±1.70	11.07±1.60	17.47±2.52
Kazail	8	0.50±0.06	0.89±0.15	7.76±1.29	12.34±1.43	12.24±1.55	19.31±2.45
Banjadid	3	0.59±0.11	1.25±0.45	10.03±2.67	11.88±1.39	14.84±2.99	23.41±4.72
Jable kofdofan	3	0.42±0.36	1.25±0.26	9.54±2.12	17.94±5.86	15.69±4.05	24.76±6.39
ElObied	12	0.43±0.12	0.73±0.15	6.03±1.47	9.09±2.67	9.46±2.02	14.93±3.19
Khortaget	9	0.46±0.04	0.85±0.04	6.69±0.47	13.60±5.24	11.39±1.73	17.98±2.72
Mosfa elobied	10	0.35±0.08	0.79±0.40	5.46±0.79	9.81±2.55	9.05±0.70	14.28±1.10
El eyarh	7	0.59±0.18	0.78±0.16	7.59±1.70	11.31±3.28	11.78±2.39	18.59±3.77
Abou haraz	13	0.45±0.08	0.83±0.15	6.61±1.82	10.65±3.72	10.59±2.40	16.71±3.79
Anumair	3	0.4±0.07	0.69±0.09	5.58±1.35	9.37±7.04	9.02±3.21	14.23±5.07
Wad mkashvi	2	0.44±0.02	0.27±0.07	6.31±1.37	7.89±4.36	9.43±2.56	14.88±4.04
Om bauid	7	0.47±0.02	0.64±0.23	5.34±2.27	9.80±1.21	8.91±2.35	14.05±3.71
Elgaka	3	0.52±0.03	0.82±0.03	7.28±0.73	11.31±1.78	11.44±0.82	18.06±1.30
Hilla sad	3	0.61±0.13	1.04±0.16	9.06±0.85	12.23±2.75	13.77±1.77	21.79±2.79
Averge ±SD		0.47±.10	0.83±0.18	7.15±1.42	11.41±3.21	11.33±2.15	17.89±3.40
Min		0.37	0.67	5.32	7.5	8.9	14.04
Max		0.59	1.12	8.8	15.4	13.87	21.88

Table (20): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in soil samples (North Kordofan).

Location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Hashaba	2	12.75±1.04	7.91±1.16	13.06±1.77	13.06±1.77	32.75±3.98	51.68±6.28
Kazail	8	15.63±2.04	9.48±1.67	12.88±1.49	12.88±1.49	38.42±4.86	60.62±7.67
Banjadid	3	18.56±3.57	13.27±4.80	13.03±3.47	12.41±1.45	47.96±11.55	75.68±18.22
Jable kofdofan	3	13.16±11.19	13.27±2.79	12.40±2.75	18.73±6.12	43.52±16.06	68.66±25.32
ElObied	12	13.69±3.75	7.77±1.62	7.83±1.91	9.48±2.79	31.67±7.38	49.96±11.65
Khortaget	9	14.39±1.35	9.06±0.45	8.69±0.61	14.19±5.47	35.68±2.91	56.30±4.59
Mosfa elobied	10	11.16±2.52	8.37±4.29	7.09±1.02	10.23±2.66	29.18±2.86	46.05±4.51
El eyarh	7	18.46±5.57	8.26±1.67	9.86±2.21	11.81±3.43	39.54±8.28	62.39±13.06
Abou haraz	13	14.10±2.52	8.79±1.65	8.59±2.36	11.12±3.89	34.22±5.53	54.00±8.72
Anumair	3	12.75±2.18	7.36±0.98	7.25±1.76	9.78±7.35	29.81±6.57	47.04±10.36
Wad mkashvi	2	13.73±0.69	7.64±0.77	8.20±1.78	8.23±4.55	31.62±4.39	49.90±6.92
Om bauid	7	14.96±0.71	6.86±2.47	6.94±2.95	10.22±1.27	31.31±5.56	49.40±8.92
Elgaka	3	16.27±0.79	8.73±0.27	9.46±0.95	11.81±1.86	37.41±1.08	59.02±1.71
Hilla sad	3	19.21±4.05	11.09±1.73	11.77±1.11	12.76±2.87	45.26±7.02	71.42±11.07
Averge ±SD		14.92±3.00	8.53±1.88	9.18±1.87	11.9±3.36	36.31±6.26	57.29±9.93
Min		11.53	7.17	6.91	7.82	29.54	46.61
Max	14	18.97	11.9	11.44	16.08	44.48	70.19

Table (21): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclide from ^{238}U, ^{232}Th series and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan).

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Kazqil	2	0.67±0.18	1.32±1.09	8.74±1.15	12.25±1.62	13.79±2.83	16.92±3.47
Tayba	2	0.57±0.23	0.79±0.28	6.41±2.28	11.27±0.69	10.60±2.82	13.01±3.46
Showshaya	3	0.58±0.23	0.87±0.54	0.87±0.54	12.20±2.32	11.57±1.29	14.20±1.58
Krkraah	2	0.75±0.07	0.91±0.18	5.94±4.45	11.27±2.08	10.43±3.67	12.80±4.51
Dubaibat	5	0.53±0.15	0.80±0.28	5.50±1.13	11.83±3.98	9.78±2.06	12.01±2.52
Dalanj	8	0.58±0.08	1.05±0.54	6.96±1.76	12.58±2.15	11.72±2.04	14.38±2.50
Al Hamadi	3	0.46±0.01	0.90±0.20	6.14±1.17	13.18±1.68	10.80±1.35	13.25±1.66
El Dilema	6	0.47±0.04	0.54±0.35	5.05±1.61	12.64±2.79	9.22±1.85	11.31±2.28
Averge ±SD		0.58±0.12	0.90±0.43	5.70±1.76	12.15±2.16	10.99±3.49	13.49±2.75
Min		0.45	0.52	4.55	9.64	8.83	10.84
Max	31	0.69	1.37	8.01	14.42	12.99	15.95

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Table (22): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan).

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Kazqil	2	0.62±0.17	1.24±1.02	8.66±1.14	12.16±1.61	13.56±2.74	16.65±3.36
Tayba	2	0.54±0.21	0.75±0.26	6.35±2.12	11.19±0.69	10.43±2.77	12.80±3.40
Showshaya	3	0.54±0.21	0.82±0.51	7.01±1.88	11.19±0.69	11.39±1.28	13.98±1.57
Krkraah	2	0.70±0.07	0.86±0.17	5.89±4.41	11.19±2.06	10.25±3.65	12.58±4.48
Dubaibat	5	0.49±0.14	0.75±0.27	5.45±1.12	11.74±3.96	9.63±2.03	11.82±2.49

Dalanj	8	0.52±0.08	0.99±0.51	6.90±1.75	12.49±2.14	11.54±2.00	14.16±2.46
Al Hamadi	3	0.43±0.01	0.85±0.18	6.08±1.16	13.08±1.66	10.65±1.33	13.05±1.63
El Dilema	6	0.44±0.04	0.51±0.32	5.01±1.60	12.54±2.77	9.09±1.82	11.15±2.24
Averge ±SD		0.54±0.12	0.83±0.41	6.42±1.90	11.95±1.95	10.82±2,20	13.27±2.70
Min		0.42	0.49	4.5	9.57	8.69	10.67
Max	31	0.64	1.29	7.94	14.31	12.78	15.69

Table (23): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordofan).

location	**Number of sample**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
Kazqil	2	0.67±0.18	1.32±1.09	8.74±1.15	12.86±1.70	13.94±2.85	28.32±4.89
Tayba	2	0.57±0.23	0.57±0.23	6.41±2.41	11.83±0.73	10.74±2.83	23.53±3.93
Showshaya	3	0.58±0.23	0.58±0.23	7.07±1.90	12.80±2.43	11.72±1.26	25.63±0.68
Krkraah	2	0.75±0.07	0.91±0.18	5.94±4.45	11.83±2.18	10.57±3.65	23.16±2.54
Dubaibat	5	0.53±0.15	0.80±0.28	5.50±1.13	12.41±4.18	9.93±2.10	23.12±6.22
Dalanj	8	0.56±0.08	1.05±0.54	6.96±1.76	13.20±2.26	11.88±2.04	26.21±3.24
Al Hamadi	3	0.46±0.01	0.90±0.20	6.14±1.17	13.83±1.76	10.96±1.36	25.75±2.61
El Dilema	6	0.47±0.04	0.54±1.61	5.05±1.61	13.26±2.93	9.37±1.86	23.27±3.62
Averge ±SD		0.57±0.12	0.83±0.55	6.48±1.95	12.75±2.27	11.14±2.24	24.87±3.47
Min		0.41	0.55	4.43	10.11	8.98	21.36
Max	31	0.67	1.27	7.55	15.13	13.15	28.42

Table (24): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in soil samples (South Kordfan)

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Kazqil	**2**	**20.97±5.72**	**13.77±11.38**	**11.82±1.56**	**13.42±1.77**	**49.92±19.10**	**61.26±23.44**
Tayba	**2**	**18.03±7.11**	**8.23±2.89**	**8.67±2.90**	**12.25±0.76**	**38.10±13.09**	**46.76±16.07**
Showshaya	**3**	**18.15±7.07**	**9.09±5.68**	**9.56±2.57**	**13.36±2.54**	**40.14±2.46**	**49.26±3.02**
Krkraah	**2**	**23.67±2.25**	**9.54±1.93**	**8.04±6.02**	**12.35±2.28**	**44.34±1.27**	**54.41±1.56**
Dubaibat	**5**	**16.58±4.76**	**8.34±2.96**	**7.44±1.52**	**12.95±4.36**	**35.60±8.12**	**43.69±9.96**
Dalanj	**8**	**17.47±2.61**	**11.04±5.66**	**9.42±2.39**	**13.78±2.36**	**41.38±8.66**	**50.78±10.63**
Al Hamadi	**3**	**14.55±0.37**	**9.45±2.05**	**8.30±1.59**	**14.43±1.84**	**35.92±3.79**	**44.08±4.65**
El Dilema	**6**	**14.76±1.20**	**5.64±3.61**	**6.83±2.18**	**13.84±3.06**	**30.68±6.25**	**37.65±7.67**
Averge ±SD	**31**	**18.02±3.89**	**9.39±4.52**	**8.76±2.59**	**13.3±2.37**	**39.51±7.84**	**48.49±9.63**
Min		**13.84**	**5.41**	**5.5**	**8.59**	**31.28**	**38.39**
Max		**21.09**	**13.28**	**10.54**	**16.46**	**44.96**	**55.18**

Table (25): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in Rocks samples.

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Jable kordofan	11	**0.50±0.15**	**0.87±0.19**	**7.10±1.55**	**11.94±1.49**	**11.45±2.00**	**14.06±2.45**
Jable Bala	4	**0.58±0.10**	**1.01±0.06**	**6.64±0.55**	**12.83±1.32**	**11.44±0.74**	**14.03±0.91**
Jable Kogoer	4	**0.58±0.04**	**0.83±0.25**	**7.05±1.45**	**12.58±1.95**	**11.61±1.71**	**14.25±2.10**
Jable Belengokaa	5	**0.57±0.04**	**0.96±0.12**	**6.29±0.95**	**12.61±0.75**	**10.98±1.07**	**13.48±1.31**
Jabl Dash	7	**0.56±0.04**	**0.97±0.09**	**7.23±1.27**	**12.98±1.58**	**12.00±1.53**	**14.73±1.87**
Averge ±SD	31	**0.56±0.07**	**0.93±0.14**	**6.86±1.15**	**12.59±1.42**	**11.50±1.41**	**14.11±1.73**
Min		**0.46**	**0.69**	**5.17**	**10.59**	**9.44**	**11.59**
Max		**0.66**	**1.06**	**8.3**	**14.31**	**13.23**	**16.23**

Table (26): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in Rocks samples.

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Jable kordofan	11	**0.47±0.14**	**0.81±0.18**	**7.04±1.53**	**11`.85±1.48**	**11.28±1.97**	**13.85±2.42**
Jable Bala	4	**0.54±0.09**	**0.95±0.05**	**6.58±0.55**	**12.73±1.31**	**11.25±0.73**	**13.81±0.89**
Jable Kogoer	4	**0.55±0.04**	**0.78±0.23**	**6.99±1.44**	**12.49±1.94**	**11.44±1.69**	**14.04±2.07**
Jable Belengoka	5	**0.54±0.04**	**0.91±0.11**	**6.24±0.94**	**12.52±0.75**	**10.81±1.05**	**13.27±1.29**
Jabl Dash	7	**0.52±0.04**	**0.91±0.08**	**7.16±1.26**	**12.88±1.53**	**11.82±1.51**	**14.50±1.85**

Averge ±SD		**0.52±0.07**	**0.87±0.13**	**6.80±1.14**	**12.49±1.40**	**11.32±1.39**	**13.89±1.70**
Min		**0.43**	**0.65**	**5.13**	**10.51**	**9.29**	**11.4**
Max	31	**0.62**	**1**	**8.22**	**14.21**	**13.02**	**15.98**

Table (27): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclide from ^{238}U, ^{232}Th series and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in Rocks samples**.**

Location	**Number of sample**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**nGy/h**	**µSv/y**
Jable Kordofan	**11**	**0.50±0.15**	**0.87±0.19**	**7.10±1.55**	**12.53±1.57**	**11.60±2.01**	**25.31±3.65**
Jable Bala	**4**	**0.58±0.10**	**1.01±0.06**	**6.64±0.55**	**13.46±1.38**	**11.59±0.75**	**26.08±1.84**
Jable Kogoer	**4**	**0.58±0.04**	**0.83±0.25**	**7.05±1.45**	**13.20±2.05**	**11.77±1.72**	**26.05±3.56**
Jable Belengokaa	**5**	**0.57±0.04**	**0.96±0.12**	**6.29±0.95**	**13.23±0.79**	**11.14±1.07**	**25.32±1.55**
Jabl Dash	**7**	**0.56±0.04**	**0.97±0.09**	**7.23±1.27**	**13.62±1.62**	**12.16±1.54**	**26.94±3.01**
Averge ±SD		**0.56±0.07**	**0.93±0.14**	**6.86±1.15**	**13.21±1.48**	**11.65±1.42**	**25.94±2.72**
Min		**0.46**	**0.69**	**5.17**	**11.11**	**9.59**	**21.94**
Max	**31**	**0.66**	**1.06**	**8.3**	**15.02**	**13.39**	**29.36**

Table (28): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclide from ^{238}U, ^{232}Th series and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in Rocks samples.

location	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Jable kordofan	11	**15.76±4.77**	**9.07±2.04**	**9.60±2.09**	**13.08±1.63**	**37.71 7.40**	**46.28±9.08**
Jable Bala	4	**18.09±3.09**	**10.57±0.60**	**8.99±0.75**	**14.05±1.44**	**41.15±4.21**	**50.50±5.17**
Jable Kogoer	4	**18.33±1.36**	**8.73 ±2.59**	**9.54±1.97**	**13.78±2.14**	**40.04±4.19**	**49.14±5.14**
Jable Belengoka	5	**18.00±1.39**	**10.09±1.23**	**8.51±1.28**	**13.81±0.82**	**40.06±3.56**	**49.16±4.37**
Jabl Dash	7	**17.62±1.31**	**10.13±0.94**	**9.77±1.72**	**14.21±1.69**	**41.08±3.07**	**50.41±3.77**
Averge ±SD	31	**17.56±2.38**	**9.72±1.48**	**9.28±1.56**	**13.79±1.54**	**40.01`±4.49**	**49.10±5.51**
Min		**14.47**	**7.25**	**7**	**11.59**	**33.3**	**40.87**
Max		**20.7**	**11.13**	**11.22**	**15.67**	**45.63**	**56**

Table (29): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using MC DRCFs and Annual effective dose (µSv/y) in foodstuff samples.

Type of food	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Maize	5	0.09±0.06	0.17±0.05	1.84±0.16	20.18±6.42	5.57±1.60	6.84±1.96
Cordia Africana	*5*	0.08±0.04	0.13±0.07	1.61±0.54	12.12±6.12	3.50±1.45	4.29±1.78
Portulaca	5	0.09±0.02	0.14±0.04	1.98±0.68	11.49±4.43	3.43±0.97	4.20±1.19
Okra	5	0.10±0.02	0.22±0.11	2.03±0.19	13.29±6.26	3.91±1.59	4.79±1.96
Molokhia	5	0.09±0.01	0.15±0.05	1.93±0.26	11.27±5.95	3.36±1.46	4.12±1.79
Peanuts	4	0.08±0.02	0.19±0.06	2.07±0.38	6.17±0.61	2.13±0.05	2.61±0.07
Averge ±SD	29	0.09±0.03	0.17±0.06	1.91±0.37	12.42±4.97	3.65±1.19	4.48±1..46
MIN		0.05	0.1	1.38	7.29	2.43	2.99
MAX		0.11	0.25	2.34	18.17	5.00	6.13

Table (30): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclide from ^{238}U, ^{232}Th series and ^{40}K as derived using MCNP DRCFs and Annual effective dose (µSv/y) in foodstuff samples.

Type of food	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Maize	5	**0.09±0.05**	**0.16±0.05**	**1.82±0.16**	**20.03±6.37**	**5.53±1.59**	**6.78±1.95**
Cordia africana	*5*	**0.07±0.03**	**0.13±0.07**	**1.60±0.53**	**12.08±6.07**	**3.47±1.44**	**4.25±1.76**
Portulaca	5	**0.08±0.02**	**0.13±0.04**	**1.96±0.68**	**11.41±4.40**	**3.40±0.96**	**4.17±1.18**
Okra	5	**0.09±0.02**	**0.20±0.10**	**2.01±0.19**	**13.19±6.21**	**3.87±1.58**	**4.75±1.94**
Molokhia	5	**0.08±0.01**	**0.14±0.05**	**1.92±0.26**	**11.19±5.90**	**3.33±1.44**	**4.09±1.77**
Peanuts	4	**0.07±0.02**	**0.17±0.06**	**2.05±0.37**	**6.12±0.60**	**2.11±0.05**	**2.58±0.07**
Averge ±SD		0.08±0.03	0.16±0.06	1.89±0.37	12.34±4.93	3.62±1.18	4.44±1.45
MIN		0.05	0.09	1.37	7.23	2.41	2.96
MAX	29	0.11	0.24	2.32	18.04	4.96	6.08

Table (31): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclidefrom ^{238}U, ^{232}Th series and ^{40}K as derived using GANT DRCFs and Annual effective dose (µSv/y) in foodstuff samples.

Type of food	**Number of sample**	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Maize	5	**0.09±0.5**	**0.17±0.05**	**1.92±0.17**	**21.12±6.74**	**5.84±1.68**	**7.16±2.06**
Cordia africana	*5*	**0.07±0.04**	**0.13±0.07**	**1.68±0.56**	**12.76±6.42**	**3.66±1.52**	**4.49±1.87**
Portulaca	5	**0.09±0.02**	**0.14±0.04**	**2.06±0.71**	**12.06±4.65**	**3.59±1.01**	**4.40±1.24**
Okra	5	**0.09±0.02**	**0.21±0.11**	**2.11±0.20**	**13.94±6.56**	**4.09±1.67**	**5.02±2.05**
Molokhia	5	**0.09±0.01**	**0.15±0.05**	**2.01±0.27**	**11.82±6.24**	**3.52±1.53**	**4.32±1.87**
Peanuts	4	**0.08±0.02**	**0.18±0.06**	**2.16±0.39**	**6.47±0.64**	**2.22±0.06**	**2.73±0.07**
Averge ±SD		**0.09±0.10**	**0.16±0.06**	**1.99±3.82**	**13.03±5.21**	**3.82±1.25**	**4.69±1.53**
MIN		**0.05**	**0.1**	**1.44**	**8.49**	**2.54**	**3.12**
MAX	29	**0.11**	**0.25**	**2.44**	**20.29**	**5.24**	**6.43**

Table (32): Absorbed dose rates in air at 1 m height (nGy/h) due to gamma emitting nuclides from ^{238}U, ^{232}Th series and ^{40}K as derived using UNSCEAR DRCFs and Annual effective dose (µSv/y) in foodstuff samples.

Type of food	Number of sample	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	nGy/h	µSv/y
Maize	5	**2.89±1.73**	**1.77±0.56**	**2.49±0.22**	**22.10±7.03**	**7.31±1.90**	**8.79±2.34**
Cordia africana	*5*	**2.36±1.17**	**1.39±0.77**	**2.18±0.73**	**13.32±6.70**	**4.81±1.93**	**5.91±2.37**
Portulaca	5	**2.84±0.57**	**1.45±0.45**	**2.68±0.92**	**12.59±4.85**	**4.89±1.22**	**6.00±1.50**
Okra	5	**2.98±0.63**	**2.25±1.15**	**2.74±0.26**	**14.55±6.85**	**5.63±2.11**	**6.91±2.59**
Molokhia	5	**2.74±0.32**	**1.56±0.52**	**2.61±0.35**	**12.34±6.51**	**4.81±1.73**	**5.91±2.13**
Peanuts	4	**2.47±0.60**	**1.94±0.67**	**2.80±0.51**	**6.75±0.66**	**3.49±0.26**	**4.28±0.32**
Averge ±SD	29	**2.71±0.84**	**1.73±0.69**	**2.58±0.50**	**14.30±5.43**	**5.16±1.53**	**6.30±1.88**
MIN		**1.56**	**1.03**	**1.87**	**7.98**	**3.55**	**4.36**
MAX		**3.57**	**2.64**	**3.16**	**19.9**	**6.9**	**8.47**

Reference:

1. Magdi Hasan Saad, Jumaa Yousif Tamboul and Mohamed Yousef (2014): Evaluation of natural Radioactivity in Different Regions in Sudan, journal of American Science, 10(2):14-18

2. Ajibode M. O M. OAvwiei, G. O and Agbalagb. E. O (2013): Evaluation of Radiation Hazard Indices in an Oil Mineral lease (oil block), Nigeria, International Journal of Engineering and Applied Sciences, 4, (2)

3. Tzortzis and Haralabos Tsertos (2003): Gamma-ray Measurements of Naturally Occurring Radioactive Samples from Cyprus Characteristic Geological Rocks. Radiation Measurement, 37 (3)

4.A.S. Alaamer (2008): Assessment of Human Exposures to Natural Sources of Radiation in Soil of Riyadh, Saudi Arabia, Turkish Journal of Engineering and Environmental Sciences, 32, 229 – 234.

4-Shousha.H.A, Ahmad. F and Belal.M,(2009):Natural Radioactivity and transfer factor for samples from spring area in Siwa oasis, western desert, Egypt, J.Isotope and Radiation Research., 41(4):971

5. Surinder Singha, Asha Rani and Rakesh Kumar Mahajan (2005): 226Ra, 232Th and 40K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry, J.Radiation Measurements, 39, 431 – 439

6. Avwiri G. O and Ononugbo C. P (2012): Natural Radioactivity Levels in Surface Soil of Ogba, Egbema,Ndoni ,Oil and Gas Fields, J.Energy Science and Technology, 4(2), 92-101.

7.S.Harb, A. H. El-Kamel, A. M. Zahran, A. Abbady and F.A. Ahmed (2014): Assessment of natural Radioactivity in soil and water samples from Adan governorate South of Yemen Region international journal of Recent Researcher in physics and chemical Sciences, l1(1), 17

8.Mahmoud Ibrahim, Osama Shalabiea and Hassan Diab (2014): Measurement of some radioactive elements in drinking water in Arar city, Saudi Arabia, American journal of life sciences, 210, 24-28

9. Mikhail Balonov (2008): Exposures from environmental radioactivity: International safety standards, J.Applied Radiation and Isotopes , 66, 1546–1549.

10. Alatise O. O., Babalola I. A, Olowofela J. A (2008): Distribution of some natural gamma-emitting radionuclides in the soil of the coastal areas of Nigeria, Journal of Environmental Radioactivity, 99, 1746-1749

11. Rani A, Singh S (2005): Natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ-ray spectrometry, J.Atmospheric Environment. 39, 6306-6314

12.A. Kurnaz , B.Kuc-ukomeroglua, R. Keser, N.T Okumusoglub,F. Korkmaz and G. Karahanc,U.C -evik (2007): Determination of radioactivity levels and hazards of soil and sedimentsamples in Fırtına Valley (Rize, Turkey),J. Applied Radiation and Isotopes, 65, 1281–1289

13.H .Taskin, M. Karavus, P. Ay and A .Topuzoglu (2009):Radionuclide concentrations in soil and lifetime cancerrisk due to gamma radioactivity in Kirklareli, Turkey, Journal of Environmental Radioactivity, 100 , 49–53.

14. Labidi S, Mahjoubi H, Essafi F and Ben Salah R (2010): Natural radioactivity levels in mineral, therapeutic and spring waters in Tunisia, J.Radiation Physics and Chemistry, 79, 1196–1202

15.Murtadha Sh, Mohamad S. Jaafar and Sabar Bauk (2013):Assessment of Radionuclide Transfer from Soil to Vegetables in Farms from Cameron Highlands and Penang, (Malaysia) Using Neutron Activation Analysis, J. Applied Physics Research, 5, - 1916-9639

16. A.Kurnaz, B.Kuc -ukomeroglua, R. Keser, N.T. Okumusoglub,F. Korkmaz, G. Karahanc,U.C -evika(2007): Determination of radioactivity levels and hazards of soil and sediment samples in Fırtına Valley (Rize, Turkey),J. Applied Radiation and Isotopes ,65 , 1281–1289.

17. Hasan M. Khan, M Ismail, K. Khanand P. Akhter (2011):Radioactivity Levels and Gamma-Ray Dose Rate in Soil Samples from Kohistan(Pakistan) Using Gamma-Ray Spectrometry, J.Chinese Physics Letters, 28,(1)

18. Michalis Tzortzis and Haralabos Tsertos (2003): Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks, J.Radiation Measurements, 37, 221 – 229

19 .E.O. Joshua,J.A. Ademola , M.A. Akpanowo, O.A. Oyebanjo and D.O. Olorode (2009): Natural radionuclides and hazards of rock samples collected from Southeastern Nigeria, Radiation Measurements, 44, 401–404

20. Bolca. M ,M.M. Saç, B. Çokuysal ,T. Karal and E. Ekdal (2007):Radioactivity in soils and various food stuffs from the Gediz River Basin of Turkey, J.Radiations Measurements, 42, 263-270

21. IAEA, (2003): Guidelines for radioelement mapping using gamma ray spectrometry data

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., Karahan, G. (2009):Radionuclides concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey,Journal of Environmental Radioactivity. 100, 49-53

22. Kurnaz A., Küçükömerğlu, B. Keser, R.,Okumusoglu, N. T., Korkmaz, F Karahan and G Cevik, U. (2007): Determination of radioactivity levels and hazards of soil and sediment samples in Firtina valley (Rize, Turkey), J.Applied Radiation and Isotopes, 65,1281-1289.

23. Singh. J, Singh H, Singh S, Bajwa B. S and Sonkawade. R. G (2009): Comparative Study of natural radioactivity levels in soil samples from the upper Siwaliks and Punjab, India using gamma-ray spectrometry, Journal of Environmental Radioactivity,100(14. November); 94-98.

24. Rani A and Singh S (2005): Natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ-ray spectrometry, Atmospheric Environment, 39, 6306-6314

25. Einas.H.O, I. Salih and A. Khatir Sam (2012): GIS mapping and assessment of terrestrial gamma-radiation in Northern state, J.Radiation Protection Dosimetry, 1-11

26.I Louw, A. Faanhof, D. Kotze and M. Willemse (2011): A first order assessment of the potential radiological impact of foodstuffs grown in a catchment area influenced by mining and mineral processing industries, J.Radioprotection,1(46),213–222

27. N.N. Jibiri, Farai .IP and Alausa .SK (2007): Estimation of annual effective dose due to natural radioactive elements in ingestion of foodstuffs in tin mining area of Jos-Plateau, Nigeria, Journal of Environmental Radioactivity, 94 , 31- 40

28.F. L. Melquiades and C. R. Appoloni (2004): Natural Radiation Levels in Powdered Milk Samples,J. Tecnol. Aliment, 24(4).

29. D. G. Marbaniang (2011): Radioactivity (Gross-A and Gross-B) Studies of Surface Water Collected from Domiasiat Area, West Khasi Hills District, Meghalaya, India, International Journal of Environmental Protection,1 , 17-21.

30. Mlwilo N A, Mohammed. N.K and Spyrou. N.M (2007): Radioactivity levels of staple foodstuffs and dose estimates for most of the Tanzanian population, Journal of Radiological Protection, l (27)

31. Buccianti. A, Apollaro. C, Bloise. A, DeRosa. R, Falcone. G, Scarciglia. F, Tallarico and A, Vecchio.G,(2009): Natural radioactivity levels (K, Th, U and Rn) in the Cecita lake area (Sila Massif, Calabria, Southern Italy): An attempt to discover correlations with soil features on a statistical base." J.Geodema. 10226, 1-12

32. Abdul Jabbar (2010): Measurement of Environmental Radioactivity and Assessment of Doses the General Public in Rechna Doab, Pakistan, PhD Thesis, COMSATS Institute of Information Technology, Islamabad, Pakistan

33. Hatem Eltayeb Fadlalla Hemada (2005): Radioactivity levels of basic foodstuffs and dose estimates in Sudan, MSc Thesis, Sudan Academy of Sciences, SAS, Atomic Energy Council, Sudan.

34.S. U. Rahman , Matiullah , F. Malik , M. Rafique , J. Anwar , M. Ziafat and A. Jabbar (2010): Measurement of naturally occurring/fallout radioactive elements and assessment of annual effective dose in soil samples collected from four districts of the Punjab Province, Pakistan, J .Radioanal Nucl Chem ,287,647–655

35.J. H. Al-Zahrani (2012): Radioactivity Measurements and Radiation Dose assessments in Soil of Albaha Region (Saudi Arabia), J. Life Science Journal, 9(3)

36. I.R. Ajayi and O.O. Kuforiji (2001): Natural radioactivity measurements in rock samples of Ondo and Ekiti states in Nigeria,J. Radiation Measurements, 33, 13-16.

37.Michalis Tzortzisa, Haralabos Tsertos , Stelios Christodes, George Christodoulides (2033): Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks, J Radiation Measurements ,37 , 221 – 229

38.K. Jeevarenuka ,G. Sankaran Pillai ,P. Shahul Hameed and R. Mathiyarasu (2014): Evaluation of natural gamma radiation and absorbed gamma dose in soil and rocks of Perambalur district (Tamil Nadu, India), J Radioanal Nucl Chem , 302:245–252

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

40.I. Louw, A. Faanhof , D.Kotze and M. Willemse (2011): A first order assessment of the potential radiological impact of foodstuffs grown in a catchment area influenced by mining and mineral processing industries , J.Radioprotection, 46(6)213–222

41. Adam Sam and Eriksson (1995): Radium-226 Uptake by Vegetation Grown in Western Sudan, J. Environmental Radioactivity, 29 (1), 27-38

42. A. K. Sam and Moawia M. Elmahadi (2007): Assessent of absorbed Dose reate in air overplowed arable lands in sinnar state, central Sudan. Radiation Protection Dosimetery.

43.Ramli .A.T, Sahrone. S, Wagiran. H (2005): Terrestrial Gamma Radiation Dose Study to Determine the Baseline for Environmental Radiological Health Practices in Melaka State, Malaysia. J.Radiol. Prot. 25, 435-450.

44. Bolca, M., Sac, M. M., Cokuysal, B., Karali, T and Ekdal, E. (2007): Radioactivity in soils and various food stuffs from the Gediz River Basin of Turkey, J.Radiations Measurements. 42; 263-270

45. Borrelli R. A. (1999): Characterization of Radioactivity in the Environment. M.Sc.thesis, Faculty of the Worcester Polytechnic Institute, Worcester, Massachusett., USA

46. Baggoura .B, Noureddine Aand Benkrid M. (1998): Level of Natural and Artificial Radioactivity in Algeria, J Appl RadiatIsot.; 49(7), 867-73

47. Buccianti.A, Apollaro. C., Bloise, A, De.Rosa. R, Falcone, G. Scarciglia .F, Tallarico and A, Vecchio.G. (2009). Natural radioactivity levels (K, Th, U and Rn) in the Cecita lake area (Sila Massif, Calabria, Southern Italy): An attempt to discover correlations with soil features on a statistical base Geodema, 10(226), 1-12

48.Banzi .F.P, Kifanga L.D and Bundala F.M(2000): Natural radioactivity and radiation exposure at the Minjingu phosphate mine in Tanzania,Journal of Radiological Protection, 20

49. Borrelli .R. A. (1999): Characterization of Radioactivity in the Environment. M.Sc.thesis, Faculty of the Worcester Polytechnic Institute, Worcester, Massachusetts, USA

50.Murtadha .Sh. Aswood, Mohamad .S ,Jaafa and SabarBauk (2013) :Assessment of Radionuclide Transfer from Soil to Vegetables in Farms from Cameron Highlands and Penang, (Malaysia) Using Neutron Activation Analysi,J. Applied Physics Research,5, (5),1916-9647

51. Mortazavi and Karam (2002): High Levels of Natural Radiation in Ramsar, Iran.Iranian Journal of Science (Germany) 2 (2), 1-9

52. UNSCEAR (1977), United Nations Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation. Report to the General Assembly, with Annexes

53. UNSCEAR (2000), United Nations Scientific Committee on the Effects of Atomic Radiation: Sources and Effects of Ionizing Radiation, Report to the General Assembly, with Annexes.

54. UNSCEAR, 1988.Sources Effects and Risks of Ionizing Radiation United Nations Scientific Committee on the effects of Atomic Radiation, Report to the general Assembly, with annexes. United Nations, New York

55. UNSCEAR (1988), United Nations Scientific Committee on the Effects of Atomic Radiation: Effects and Risks of Ionizing Radiation. Report to the GeneraAssembly, with Annexes

56. Sam A. K., Ahmed M. M. O., El Khangi F. A.,El Nigumi Y. O and Holm E (1997): Assessment of Terrestrial Gamma Radiation in Sudan,J Radiation Protection Dosimetry 71:141-145

57. Sam A.K. et al. (2002): Assessment of Gamma Dose Rate over a Suspected Uranium Mineralization Area of Gebel Mun, Western Sudan. J.Radiation Protection Dosimetry102,169-174

58. Sam A. K and Sirel khatim D. A (2003): Comparative Study on the Evaluation of Gamma .Dose Rate above Uranium Mineralization Areas in Western Sudan, J. Radiochim.Acta91, 409-412

59. Sam A.k., Sirelkhatim D.A., Hassona R.k., Hassan R.K., Hag Musa E and Ahmed M.M.O (2002): Assessment of Gamma Dose Rate over a Suspected Uranium Mineralizatio in Area of Gebel Mun, Western Sudan. Radiation Protection Dosimetry102, 169-174.

60. Babikiret al. (2000): Measurement of Some Natural Radionuclides in ElgasArea (Sudan). Proceedings of the Fourth Arab on the Peaceful Uses of Atomic Energy, (Tunis: 14-18/ 11/1998), IV, 443-455

61. Sam. A. Kh and Holm. E (1995): The natural radioactivity in phosphate deposits from Sudan, The Science of the Total Environment.162; 173-178

62. N .A. Mlwilo, N. K. Mohammed and N. M Spyrou(2007): Radioactivity levels of staple foodstuffs and dose estimates for most of the Tanzanian populat, Journal of Radiological Protection, 27, 471-480

63. Yücel.H., Cetiner, M.A., Demirel. H (1998) Use of the 1001 keV peak of 234mPa daughter of 238U in measurement of uranium concentration by HPGegamma-ray spectrometry,Nuclear Instruments and Methods in Physics Research ,A413, 74–82

64. Rani. A, Singh.S (2005): Natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ-ray spectrometry". AtmosphericEnvironment.39; 6306-6314

65. J. A. S. J̊nior, J. J. R. F. Cardoso, C. M. Silva, S. V. Silveira and R. S. Amaral (2006): Determination of radionuclides in the environment using gamma spectrometry, Journal of Radioanalytical and Nuclear Chemistry, 269(2), 451–455

66. Tawfik A. Al Kuasayer and A.bdullaNowman Al Haj (1987) Measurement of the natural radiation background level of Riyadh city, J. Transaction of American Society, 55(2),87-89

67. Osterhuis. L (1992): Radiological Aspects of the Non-Nuclear Industry in the Netherlands Radiation Protection Dosimetry, 45 (1-4), 703-705

68. Harb .S (2004):On the human radiation exposure as derived from the analysis of natural and man-made radionuclides in soil. PhD Thesis, VomFachbereichPhysik der University Hannover

69. Malanco.A, Pessina .V, Dallara. G (1993): Assessment of the Natural Radioactivity in the Brazilian State of Rio Grande Do Norte, Health Phys. 65(3), 298-302

70. Mortazavi and Karam (2002): High Levels of Natural Radiation in Ramsar, Iran. Iranian Journal of Science (Germany) 2 (2)

71.Mireles. F, Dávila. JI, Quirino. LL, Lugo .JF, Pinedo. JL, Ríos. C (2003): Natural Soil Gamma Radioactivity Levels and Resultant Population Dose in the Cities of Zacatecas and Guadalupe, Mexico, Health Physics.84 (3):368-372

72. Matiullah, Ahad. A, Ur. Rehman .S, Ur .Rehman. S, Faheem. M; Matiullah (2004): Measurement of Radioactivity in Soil of Bahawalpur Division, Pakistan, J. Radiation Protection Dosimetry, 112(3), 443-447

73. Tzortzis .l Svoukis. E, Tsertos .H (2004): A Comprehensive Study of Natural Gamma Radioactivity Levels and Associated Dose Rates from Surface Soils in Cyprus,J.Radiation ProtectionDosimetry, 109, 217-224

74. Probonas .M. and Kritidis .P (1993): The Exposure of The Greek Population to Natural Gamma Radiation of Terrestrial Origin, J. Radiation Protection Dosimetry, 46.123-126

75. White.R.E (1987): Introduction to the Principles and practices of soil science, Black well Publication.

76. Darko. E. O (2001): Natural Radioactivity in Soils and Rocks within the Greater AccraRegion of Ghana. Journal Of Radio analytical And Nuclear Chemistry, Volume 249(3), 629-632

77. Shagjjamba. D and Zuzaan. P (2004): Results of Radiation Level Study in Some Territories of Mongolia. Phy.of particles and nuclei letters, (3), 65-6

78. Eisenbud. M., (1987): Environmental Radioactivity from Natural, Industrial and Military Sources, Academic Press, Inc

79. National Council on Radiation Protection and Measurements (1992): Exposure of the Population in the United States and Canada from Natural Background Radiation" NCRP Report No. 94

International Atomic Energy Agency (IAEA), Exposure to Radiation from Natural Sources [online].http://www-ns.iaea.org/tech-areas/rw-ppss/exposure-to-natural-radiation.htm [Accessed26 Aug 2007]

80. Quindos L. S,Fernández. PL, Soto. J, Ródenas .C and Gómez. J (1994): Natural Radioactivity in Spanish Soils, Health Phys, 66(2):194-200

81. Bolca. M, Sac. M. M., Cokuysal B., Karali.T and Ekdal. E (2007): Radioactivity in soils and various food stuffs from the Gediz River Basin of Turkey, Radiations Measurements, 42, 263-270

82. Kurnaz. A, Küçükömerğlu. B. Keser, R. Okumusoglu, N. T., Korkmaz, F., Karahan. G, Cevik. U (2007): Determination of radioactivity levels and hazards of soil and sediment samples in Firtina valley (Rize, Turkey),J. Applied Radiation and Isotopes. 65, 1281-1289

83. IAEA (1990): Practical aspects of operating a neutron activation analysis laboratory, IAEA, Technical Report. 564. Vienna: IAEA