CHAPTER ONE

1. INTRODUCTION

1.1 Background radiation

Human beings are exposed to background radiation that stems both from natural and man-made sources. Natural background radiation, which is equivalent to 2.4mSv per person, makes up approximately 80% of the total radiation dose a person is exposed to in a year (Taskin et. al., 2009).

The world is naturally radioactive, and a round 90% of human radiations, exposure to radon gas, and terrestrial radiations. (Rani and Surinder, 2005).

The 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 has 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).

Natural radioactivity arise mainly from the primordial radionuclides such as ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th and their decay products, which are present trace levels in all ground formations. The knowledge of concentrations and distributions of radionuclides in these materials are of interest since it provides useful information in the monitoring of environmental radioactivity (Bolca et. al., 2007).

The naturally occurring radionuclides present in soil include ^{226}Ra, ^{232}Th and ^{40}K. Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soils and rocks play an important role in radiation protection

and measurement. Some of the exposures are fairly constant and uniform for all individuals everywhere, for example, the dose from ingestion of ^{40}K in foods. Other exposures vary widely depending on location. Cosmic rays, for example are more intense at higher altitudes and concentrations of uranium and thorium in soils are elevated in localized areas. Only nuclides with half-lives comparable with the age of the earth or their corresponding decay products, existing in terrestrial materials, such as ^{40}K, ^{238}U and ^{232}Th radionuclides are of great interest (Bolca et. al., 2007; Rani and Surinder, 2005).

Abnormal occurrence of uranium and its decay products in rocks and soils and thorium in monazite sands are the main source of high natural background areas that have been identified in several areas of the world, e.g., Yangjiang in China, Rasmar in Iran, Kerala cost of India, etc. (Bolca et. al., 2007; Rani and Surinder, 2005). Therefore, measurements of natural radioactivity in soil are of a great interest for many researchers throughout the world, which led to worldwide national surveys in the last two decades. The accumulation of such radioactivity may substantially contribute to the collective radiation dose received by the local population living within this particular environment. Radiation exposure can damage living cells, causing death in some of them and modifying others. All living organisms are continually exposed to ionizing radiation, which has always existed naturally. Naturally occurring radionuclides of terrestrial origin (also called primordial radionuclides) are present in various degrees in all media in the environment, including the human body itself.

Irradiations of the human body from external sources are mainly by gamma radiation from radionuclides in the ^{238}U and ^{232}Th series and from ^{40}K. Some other terrestrial radionuclides, including those of the ^{235}U series, ^{87}Rb, ^{138}La, ^{147}Sm and ^{176}Lu, exist in nature but at such low levels that their contributions to the dose in humans are small. There have been many surveys to determine the background levels of radionuclides in soil, which can in turn be related to the absorbed dose rates in air. All of these spectrometric measurements indicate that

the three components of the external radiation field, namely from the γ-emitting radionuclides in the ^{238}U and ^{232}Th series and ^{40}K, made approximately equal contributions to the externally incident γ-radiation dose to individuals in typical situations both outdoors and indoors. (Rani and Surinder, 2005).

Natural radioactivity is wide spread in the earth's environment; it exists in soil, plants, water and air (Degerlier et. al., 2008).

Radioactive substances are ubiquitous in the environment and this inevitably leads to the radiation exposure of both humans and biota (plants, animals, etc.). The radiation exposure of humans and biota may result in adverse health effects. The discipline of the radiation protection is therefore concerned with the control and minimization of such radiation exposures. In the international context recommendations on the control of radiation exposure due to environmental radioactivity are systematically developed by International Commission on Radiological Protection (ICRP) and, on this basis, relevant international safety standards are established by the International Atomic Energy Agency (IAEA) in collaboration with other international organizations (Balonov, 2008).

1.2 Problem statement

Geographic structure of Nuba Mountains as well as rocks that are rich in phosphate, granite and salt contain 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.

Many exposures to natural radiation sources are modified by human practices. In particular, natural radionuclides are released to the environment in mineral processing and uses, such as phosphate fertilizer production and use and fossil fuel combustion, and medical procedures for most individuals, the natural background exposures are much more significant than exposures caused by man-made sources. This is problem statement because the activity concentrations of these radionuclides and their decay products exist in

significant quantities in soil, rock and water supplies in these areas may pose potential health risk. The radiological impact to human population from the environment is mainly caused by inhalation of contaminated air especially with radon gas and other radionuclide particulate, consumption of agricultural products, and water sources and also soil and rock have been used as the building materials.

1.3 Research aims

The overall aims of this research will be summarized as follows:

1. To determine natural radionuclides activity concentrations in soil of various locations in northern and eastern Nuba Mountains.
2. To determine the activity concentrations of radionuclides in different agricultural crops grown in that areas.
3. To systematically measure the terrestrial gamma radiation.
4. To determine its contribution to the annual effective dose equivalent to the population at that areas.
5. To provide necessary information of human health risks associated with terrestrial radioactivity and its effects on plant materials.
6. Establish base-line data on the gamma background radiation levels in different areas of Nuba Mountains.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Theory of radiation

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).

In α and β decay processes, an unstable nucleus emits α or β particles as it tries to become a more stable nucleus.

If a number of N radioactive nuclei are present at time t, then the number dN of nuclei decaying in a time dt is proportional to N, and so

$$\boldsymbol{\lambda} = -\left[\frac{\boldsymbol{dN/dt}}{\boldsymbol{N}}\right] \qquad (2.1)$$

Where: λ is the decay constant.

Integrating equation (2.1) led to exponential law of radioactive decay i.e.

$$N(t) = N_0\, e^{-\lambda t} \qquad (2.2)$$

Where: N_0 is constant, which is the original number of nuclei presented at t = 0.

The half-life ($t_{½}$) is the time necessary for half of the nuclei to decay (Sproul, 1980) that is $N = N_0/2$ and therefore, $N_0/2 = N_0 e^{-\lambda t}$, then half life time is,

$$t_{½} = \frac{0.693}{\lambda} \qquad (2.3)$$

Rutherford in 1909 stated that, alpha is helium $\left({}_2^4He\right)$ nuclei. The following process can present the spontaneous emission of alpha particles:

$${}_z^AX \rightarrow {}_{z-2}^{A-4}X_{N-2}^{\backslash} + \alpha\ \left({}_2^4He\right) \qquad (2.4)$$

Where: A is the atomic mass number, Z is the number of protons, N is the number of neutrons X and $X^{\backslash}$ are the original and daughter nuclei respectively (Sproul, 1980).

Beta- decay is the emission of electrons and positrons from the nucleus in radioactive decay. Inverse process of electron emission is the capturing of electron by a nucleus from its atomic orbit (Sproul, 1980). The most basic β decay process is the conversion of proton to neutron or of a neutron to proton; therefore, β-decay changes both Z and N by one unit (Z→Z ± 1, N→N ± 1), so that A = Z+N remains constant.

The basic β-decay processes are thus:

$${}^{A}_{Z}X_{N} \rightarrow {}_{z+1}{}^{A}X_{N-1} + \beta^{-1} + \acute{\upsilon}\ or(n \rightarrow p + \bar{e}(\beta^{-}) + \acute{\upsilon})\ eletron\ emission.. \quad (2.5)$$

$${}^{A}_{Z}X_{N} \rightarrow {}_{z-1}{}^{A}X_{N+1} + \beta^{+} + \nu\ or\ (p \rightarrow n + e^{+}(\beta^{+}) + \nu)\ positron\ emission \ldots\ldots \quad (2.6)$$

$${}^{A}_{Z}X_{N} \rightarrow {}_{z-1}{}^{A}X_{N+1} + \nu\ or\ \ (p + \bar{e} \rightarrow n(\varepsilon) + \nu)\ electron\ capture \quad \ldots\ldots\ldots (2.7)$$

Where: υ and ύ are neutrino and antineutrino respectively, which are highly penetrating radiation (Sproul, 1980).

2.1.1 Gamma decay

In 1900 Villard (Mann et. al., 1980) had found a type of radiation with more highly penetrating property emitted by radium, this radiation was given the name gamma-ray.

Most alpha and beta decays, and most nuclear reactions as well, produce nucleus in an excited state. These excited states decay rapidly to a lower excited state or to the ground state through the emission of one or more gamma-rays, which are photons of electromagnetic radiation of energy equal to the difference in energy between the nuclear states. Gamma rays were observed in all nuclei that have excited bound states (A>5), and usually follow alpha and beta decay since those decays will often lead to excited states in the daughter nucleus. Gamma-rays have energies typically in the range of 0.1 to 10 MeV, and thus corresponding wave length between 10^{-19} and 10^{-13} meters (Krane, 1988).

Gamma-rays interact with matter by imparting energy to atoms and there by raising electrons to higher energy levels within the atom (excitation) or removing the electron entirely from the atom (ionization). Eventually all of the

energy given in ionizing events is dissipated in atomic or molecular excitation. In addition, γ-radiation will lose energy by the creation of electron-positron pairs. Method of γ-interaction depends upon the photon energy.

2.2 Natural gamma radiation

The most common source of ionizing radiation received by humans is the natural environmental radiation. Background radiation levels are usually from a combination of terrestrial and cosmic radiations. All common rock types and the soils derived from them contain natural radioactive elements. Presence of these radio elements is apparent in any γ-ray survey (IAEA, 1979).

2.2.1 Cosmic radiation

High energy primary cosmic rays interact with matter in the upper atmosphere, and produce protons, helium nuclei, electrons, photons and neutrinos. These particles interact with atmospheric air and produce: ^{3}H, ^{7}Be, ^{10}Be, ^{22}Na,^{24}Na and^{14}C(UNSCEAR, 1988). The dose from cosmic radiation varies in different parts of the world due to differences in elevation and to the effects of the earth's magnetic field (NCRP, 1995).

2.2.2 Terrestrial radiation

The terrestrial component of the natural background is dependent on the composition of the soils and rocks, containing natural radionuclide (Kurnaz et. al., 2007). Gamma radiation emitted from naturally occurring radioisotopes, also called terrestrial background radiation, represents the main external source of irradiation of the human body. Natural environmental radioactivity and associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world. A significant part of the total dose contribution in the form of natural sources comes from terrestrial gamma radionuclides. Only

nuclides with half-lives comparable with the age of the earth or their corresponding decay products, existing in terrestrial materials, such as ^{40}K, ^{238}U, and ^{232}Th are of great interest. (Bolca et. al., 2007). These radionuclides are mainly responsible for internal exposure, through ingestion of food and water, and through inhalation of air particulates-of special concern are the long-lived alpha emitters of the uranium decay chain (Amaral et. al., 2005). The 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 present in varying amounts in soils, building materials, water, rocks, and atmosphere (Singh et. al., 2009; Tso and Leung, 2000).The most common terrestrial radioelements, which produce γ-radiation, are potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th). Whereas potassium undergoes a simple form of radioactive decay, the decay of uranium and thorium is complex, and proceed sequentially along series of disintegrations.

2.2.2.1 Potassium (K)

Potassium has a simple form of radioactive decay, as shown in table (2.1) below. Only one (^{40}K) of the several natural isotopes of potassium is radioactive. It has a relative isotopic abundance of 0.0118%. During decay ^{40}K produces two daughter isotopes, ^{40}Ca and ^{40}Ar, with the emission of beta and gamma radiation. Because of the simple scheme it is characterized by a single α-energy, 1.46MeV. Potassium has a specific gamma activity of $0.003x10^6$ Bq/kg. The use of fertilizer in large extent have effected radionuclides concentration, especially potassium containing fertilizers are the one of cause for presence of high activity of ^{40}K in soil (Akhtar et. al., 2005; Buccianti et. al., 2009).

Table (2.1): Characteristics of the ^{40}K decay scheme

Decay scheme	Half-lives of isotopes	Radiation	Gamma per disintegration	γ-ray energy (MeV)
^{40}K	$1.3x10^9$ years	β, γ	0.11	1.4608
(89%) ^{40}Ca +β	Stable			
(11%) ^{40}Ar+α	Stable			

2.2.2.2 Uranium (U)

Natural uranium consists principally of three main isotopes, with different relative abundance, ^{238}U with half life $4.468x10^9$ years (99%), and ^{235}U with half life $7.038x10^8$ years (0.71%), and ^{234}U with half life $2.445x10^5$ years (0.006%) (Buccianti et. al., 2009). The radioactive decay of ^{238}U as shown in table (2.2) is complex and passes through 14 steps, each with characteristic disintegration and daughter products before it reaches the final and stable end product ^{206}Pb. Uranium and its products are more radioactive than potassium, the specific activity of ^{238}U is (12.23 ± 0.027) x 10^6Bq/kg of total uranium. The principal gamma emission is associated with the uranium product ^{214}Pb and ^{214}Bi. The cumulative half-lives of decay products up to ^{214}Pb and ^{214}Bi formation are approximately 330 x 10^3 years (IAEA, 1979). ^{226}Ra is a member of ^{238}U series is considered as the highly radiotoxic natural radio nuclide (Akhtar et .al., 2005).

Table (2.2): Principal characteristics of the ^{238}U decay series

Isotope	Half-lives	Principal radiation	Gamma per disintegration	Principal γ-ray energy (MeV)
$^{238}U_{\downarrow}$	4.51 x 10^9years	α		
$^{234}Th_{\downarrow}$	24.1 days	β	0.08	
$^{234}Pa_{\downarrow}$	1.18 min	β		
$^{234}U_{\downarrow}$	2.48 min	α		
$^{230}Th_{\downarrow}$	8.0 x 10^4 years	α		
$^{226}Ra_{\downarrow}$	1.6 x 10^3 years	α	0.04	

$^{222}Rn_{\downarrow}$	3.82 days	α		
$^{218}Po_{\downarrow}$	3.05 min	α		
$^{214}Pb_{\downarrow}$	26.8 min	β, γ	0.60	0.29, 0.35
$^{214}Bi_{\downarrow}$	19.8 min	β, γ	1.30	0.61, 1.12, 1.76
$^{214}Po_{\downarrow}$	1.6 x 10^{-4} sec	α		
$^{210}Pb_{\downarrow}$	21.3 years	β	0.04	
$^{210}Bi_{\downarrow}$	5.01 days	β		
$^{210}Po_{\downarrow}$	138.4 days	α		
$^{206}Pb_{\downarrow}$	Stable			

2.2.2.3Thorium (Th)

Thorium ischaracterizedby twenty seven radioisotopes with most abundant. ^{232}Th with a half-life of about 14.05 billion years. Other important isotopes are ^{230}Th with half-life of 75.380 years, ^{229}Th with half-live of 7340 years and ^{228}Th of 1.92 years. All of remaining radioactive isotopes have a half-life that is less than thirty days and the majority of these have a half-live are less than 10 min (Buccianti et. al., 2009). Naturally occurring thorium has a long half life of 14 billion years. ^{232}Th is the principal isotope of natural thorium and has a complex process before reaching ^{208}Pb as shown in table (2.3). The strongest gamma-ray emitting daughter is thallium (^{208}Ti). The cumulative half-life up to ^{208}Ti in the decay series is approximately eight years. The specific activity of ^{232}Th is 4.1 x 10^{6}Bq/kg of total thorium (IAEA, 1979).

Table (2.3): Principal characteristics of the ^{232}Th decay series

Isotope	**Half-lives**	**Principal radiation**	**Gamma per disintegration**	**Principal γ-ray energy (MeV)**
$^{232}Th_{\downarrow}$	1.39 x 10^{10} years	α		
$^{228}Ra_{\downarrow}$	5.75 years	β		
$^{228}Ac_{\downarrow}$	6.13 hours	β, γ	0.68	0.91, 0.96

$^{228}Th_{\downarrow}$	1.91 years	α	0.02	
$^{224}Ra_{\downarrow}$	3.64 days	α	0.04	
$^{220}Rn_{\downarrow}$	55.3 sec	α		
$^{216}Po_{\downarrow}$	0.15 sec	α		
$^{212}Pb_{\downarrow}$	10.64 hours	β, γ	0.52	0.24
$^{212}Bi_{\downarrow}$	60.6 min	β, γ	0.12	0.37
$^{212}Po_{\downarrow}$	3×10^{-7} sec	α		
$^{208}Ti_{\downarrow}$	3.1 min	β, γ	2.3	0.51, 0.58, 2.62
$^{208}Pb_{\downarrow}$	Stable			

2.3 The radioactivity of the earth's crust

The radioactivity of the earth's crust is generally from minerals from which the rocks of the earth and soils derived from them are built. All measurements that were carried out in surveys for radioactive ores revealed that the radioactivity was very unevenly distributed over the volume of the crust and lithosphere. It is related to the circumstances and geological structures. (Buccianti et. al., 2009).

2.3.1 Radioactivity of 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. The isotope ^{40}K emits gamma-rays with energy of 1.461 MeV, thus the determination of K is considered as direct. The concentration of K is given in mass percentage. The determination of U is based on the detection of the ^{214}Bi radionuclide, which is a member of the ^{238}U decay series emitting the energy of 1.76 MeV. In the case of U, the detection is therefore indirect and the concentration is given in ppm eU (equivalent of uranium). The determination of Th contents is indirect as referred to the ^{208}Ti

radionuclide with energy of 2.615 MeV, originating from the ^{232}Th decay series. The concentration of This given in ppm eTh. (Bucciant et. al., 2009).

Uranium is preferentially concentrated in the earth's crust and there is relationship between the type of igneous rocks and its uranium content or granitic rocks have the highest concentrations (2-10 mg kg^{-1}), basaltic rocks contain lower concentration (0.3- 0.8 mg kg^{-1}) while the concentrations is sedimentary rocks show wide range (Buccianti et. al., 2009; Rani and Surinder, 2005).Phosphate rocks are the starting material for the production of all phosphate products and the main source of phosphorus for fertilizers. It is well known that phosphate rocks generally have enhanced concentrations of naturally occurring radionuclides. Phosphatic fertilizers are produced from rock phosphate which is known to contain elevated natural ^{238}U and its daughter products (Bolca et. al., 2007; Sam and Holm, 1995).Volcanic geographic structures as well as rocks that are rich in phosphate, granite and salt contain natural 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. (Taskin et. al., 2009).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).The continued wide spread use of phosphate fertilizers many eventually result in a measurable increase in background radiation levels due to the presence of uranium isotopes and their decay products in fertilizers manufactured from phosphate rocks (Ekdal et. al., 2006).

The manufacture and agricultural land during cultivation, as well as contamination of the air and water supplies. Hence, phosphates have a potential radiological health concern in addition to their chemical toxicity. Typical

concentration of U in phosphate rock range between 30 and 260 ppm (Bolca et. al., 2007).

2.3.2 The radioactivity of soil

The main source of continuous radiation exposure to human, soil acts as a medium of migration for transfer of radionuclides to the biological systems and hence, it is the basic indicator of radiological contamination in the environment. Moreover, the soil radioactivity is usually important for the purposes of establishing baseline data for future radiation impact assessment, radiation protection and exploration (Al-Hamarneh and Awadallah, 2009). Various studies concerning radioactivity bound to soil were carried out in many countries, such as:(Khatir et. al. 1998; Tzortzis et. al. 2003; Matiullah et. al 2004; Ramli et. al. 2005; Veiga et. al. 2006; El-Bahi et.al.,2005) and many others. Most of these studies were concentrated on natural sources as the natural radiation is largest contributor to the external dose of the world population (Al-Hamarneh and Awadallah, 2009).

Soil is a mixture of natural bodies on the earth surface containing living matter and supporting plants. Soil is a complex substance because of its extreme variability in physical and chemical composition. It contains small but significant quantities of organic and inorganic compounds, which are essential for the growth of plants. There are many types of soil depending upon the physical and chemical composition. The soil classified as saline, saline sodic and alkali, etc. in saline soil, the concentration of salts is increased to the level at which the crop growths adversely affected. Saline soils have a high content of natural salts and have pH generally above 7.3 and not over 8.5.Soil not only consists of organic and inorganic compounds but also radionuclides, i.e. uranium, thorium, radium, potassium-40, etc, which occur in nature as a complex of oxides, hydrated oxides, carbonates, phosphates, sulphates vanadates and silicates (Akhtar et.al., 2005).In addition to the natural sources, soil

radioactivity is also affected from man-made activities. Caesium-137 (^{137}Cs) is a fission product which is formed through nuclear tests and accidents. The deposition of ^{137}Cs in soil is important since its half-life is 30.2 years and it has a gamma emission of 661 KeV.

Radioisotopes that are present in soil significantly affect terrestrial gamma radiation levels. In the last decade, several studies were carried out to assess the average outdoors terrestrial gamma dose rate in air at 1m from the ground. These studies determined that the effective gamma radiation levels were generally in the range of 10-200 nGy/h with a mean of 60 nGy/h (Taskin et .al., 2009).

The radioactivity of soils is essential for understanding changes in the natural radiation background. Soil contains small quantities of radioactive elements U and Th along with their progeny. The main sources of the external γ-radiation are the radionuclides of the U, Th series and ^{40}K. The natural radioactivity of soil and sediment depends on the soil and sediment formation and transport processes that were involved since soil and sediment formation; chemical and biochemical interactions influence the distributions patterns of uranium, thorium and their decay products (Kurnaz et. al., 2007).

There have been many surveys to determine the background levels of radionuclides in soils, which can in turn be related to the absorbed dose rates in air. All of these spectrometric measurements indicate that the three components of the external radiation field, namely from the γ-emitting radionuclides in the ^{238}U and ^{232}Th series and ^{40}K, made approximately equal contributions to the externally incident γ-radiation dose to individuals in typical situations both outdoors and indoors. Since 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products, the contribution from the ^{238}U and other ^{226}Ra precursors are normally ignored (Rani and Surinder, 2005; Singh et al., 2009).

Nationwide surveys have been carried out to determine the radium equivalent activity of the soil samples in many countries. Such investigations can be useful for both the assessment of public dose rates and performance of epidemiological studies, as well as to keep reference-date records, to ascertain possible changes in the environmental radioactivity due to nuclear, industrial, and other human activities (Singh et. al., 2009).The natural radioactivity in soils comes from ^{238}U, ^{232}Th and from natural ^{40}K. Some other terrestrial radionuclides, including those of the ^{235}U series, ^{87}Rb, ^{138}La, ^{147}Sm and ^{176}LU exist in nature but at such low levels that their contributions to the dose in the humans are small (Singh et. al., 2009). Natural radionuclides in soil generate a significant component of the background radiation exposure of the population. Gamma radiation intensity in a region depends on soil and geographic structure (Singh et. al., 2009).

The contribution of natural radionuclides to absorbed dose in air depends on the concentration of radionuclide in soil. There is a direct correlation between terrestrial gamma radiation and radionuclide concentration in soil (Degerlier et. al., 2008). The specific levels are related to the type of rock from which the soil originates (Rani and Surinder, 2005).Natural radionuclides (^{238}U and ^{232}Th series nuclides and ^{40}K) in soil are derived primarily from underlying bedrock. Distribution of these nuclides is governed by weathering, sedimentation, leaching, sorption and precipitation from percolating water or dilution with other materials with different composition, resulting in great variability in their activity concentrations (Fujiyoshi and Sawamura, 2004).

Monitoring of any release of radioactivity material to the environment is necessary for environmental protection. Measurement of natural radioactivity in soil is very important to determine the amount of change of natural background activity with time as a result of any radioactivity release (Yalcin and Gurler, 2007).

2.3.3 Radioactivity of water

The water demand is supplied by surface water and ground water. Surface and ground water sources are known to contain trace elements, some of which have been widely implicated in human health and disease. A measurement of concentrations of trace elements in different water supplies is extremely important for proper assessment of the hazards associated with their intake (Yalcin and Gurler, 2007). All water on the earth has some radionuclides. According to (Kogan et. al., 1971) the concentration of uranium and thorium in water is 10^3 to 10^4 times lower than in rocks and soils. In closed water reservoirs in areas poor in atmospheric precipitation, concentration of uranium may reach 10^{-6} % to 10^{-15}%. The concentration of radioactive elements in seawater varies with depth. Thus, the concentration of radium varies between $0.5x10^{-14}$% and $0.9x10^{-14}$% in the surface layers, decreasing to between $0.1x10^{-14}$% and $0.2x10^{-14}$% at depth approximately 500 meters, increasing again at greater depth, reaching $1.0x10^{-14}$% and $1.8x10^{-14}$% at the sea bottom. The concentration of potassium in seawater is approximately 0.035% remaining constant in a given basin, and in different sea basin (Kogan et. al., 1971). Table (2.4) shows the concentration of some radioisotopes in water. (Kogan et .al., 1971).

Table (2.4): Concentration of some radioisotopes in water (Kogan et. al., 1971)

Isotope	**Sea water**		**Continental waters**	
	Concentration%	Ratio of actual to equilibrium concentration	Concentration%	Ratio of actual to equilibrium concentration
^{238}U	$3.0x10^{-7}$	1.0	$1.3x10^{-7}$	1.0
^{230}Th	$<3.0x10^{-14}$	<0.56	$1.5x10^{-12}$	0.65
^{226}Ra	$1.0x10^{-14}$	0.09	$0.7x10^{-14}$	0.15
^{222}Rn	$6.3x10^{-6}$	0.91	10^{-15}	-3.0
^{40}K	$4.2x10^{-6}$	-		
^{232}Th	$<2.0x10^{-9}$	-	$2.0x10^{-9}$	

Most recent studies have been carried out on the ground water supplies are especially from radon (^{222}Rn). Since ^{222}Rn is not typically found in surface water sources and according to (Milvy and Cothern, 1990) large public ground water system have lower concentrations (Watson et. al., 1993), smaller ground water systems were thus given most of the attention. One of the major problems in using ground water sources is the possible presence of natural occurring radionuclides, the most important of which are ^{234}U, ^{238}U, ^{226}Ra, ^{228}Ra and ^{222}Rn. As reported by (Alabdula'aly, 1996), the health risks that are connected to inhalation and ingestion for radon and its progeny. The two diseases of great concern that are usually caused by radon are stomach cancer and lung cancers respectively due to ingestion and inhalation processes.

(Watson et.al.,1993) stated that the differences in the ground water radioactivity concentrations especially for radon, for the different regions are due to the geology and uranium content of each region. They have stated that radon concentration is significant even in a region with naturally low concentrations of uranium in soil, that as many as 30% of private wells have concentrations exceeding the proposed standard value of 11-1 Bq/L (300 pci/L) for public drinking water.

2.3.4 Radioactivity of plant

The primordial radionuclides U, Th, Ra and ^{40}K are present in soil, in varying concentrations, related to the nature of the parent rock during soil genesis. Soil-plant-man is recognized as one of the major path ways for transfer of radionuclides to human being. These long-lived naturally occurring radionuclide may get transferred to plants along with the nutrients during mineral uptake, accumulate in various parts and even reach the edible portions. These plant or their parts when consumed by man would lead to continuous radiation dose. Thus the spatial variability of natural radioactivity in soil associated radiation

exposures through specific food materials is an important study (Pulhani et. al., 2005; Copplestone et. al., 2001).

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; Rudge et. al 1993).

Data on the soil-plant transfer of ^{226}R in terrestrial ecosystems are rather limited. Recently, however, IAEA published a comprehensive review pertaining to the environmental behavior of radium (IAEA, 1990). The plant intake from soil is influenced by biotic and a biotic environmental variables such as the type of soil and crop plant, pH level, soil content of organic matter, clay, other alkaline-earth elements, exchangeable calcium (a radium analog) and potassium, and chemical form and plant availability of radium in the soil (Sam and Eriksson, 1995).

Vegetables may be subjected to direct and indirect contamination of uranium series radionuclides, mainly by ^{210}Po and ^{210}Pb. The direct contamination of vegetables occurs by the deposition of radioactive particles from the atmosphere onto the above-ground parts. Primary direct deposition involves three processes: deposition, interception and retention. Indirect contamination refers to the sorption of radionuclides from the soil by the root system. In addition, activity already deposited on the ground may be re-deposited on vegetables by the wind, and then transferred to vegetables.

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).

2.4. Environmental radioactivity

Natural radionuclides include renewable cosmogenic radionuclides (^{3}H, ^{14}C, ^{22}Na, etc.) and very long-lived primordial radionuclides and their daughter (^{40}K and the ^{238}U, ^{235}U, ^{232}Th chains). The amount of the former is basically constant because of equilibrium between their rate of creation by cosmic radiation and their radioactive decay. The amount of very long-lived primordial radionuclides has decreased slowly with time since the creation of the earth as a result of radioactive decay. The environmental concentrations of both types of radionuclide are subject to significant geographical variations. In some industrially processed materials, the concentration of natural radionuclides is reduced (e.g., depleted U) or enhanced (e.g., phosphate fertilizers, ore concentrates, etc.) compared with naturally occurring material. Man-made radionuclides have been released to the environment from nuclear weapons production. (Mainly in the period 1940s- 1950s), from nuclear weapons testing as global and local fall-out (mainly in the period 1940s – 1950s) or from accidents. They are uranium and plutonium fission or neutron activation products, i.e., ^{131}I, ^{137}Cs, ^{90}Sr, ^{106}Ru, ^{144}Ce, ^{239}Pu, etc. as well as tritium. These radionuclides were released in large amount in the early period of nuclear weapons production and testing both because of the imperfection of the existing

technology and also because, at that time, there was a lack of knowledge about the adverse effects of radiation on humans and biota and, therefore there were no international environmental radiation protection standards (Balonov, 2008).

The main pathways of human exposure from environmental radioactivity are external exposure due to gamma radiation and internal exposure as result of inhaled radionuclides (mainly, radon and its daughters) and radionuclides ingested with food and drinking water. The contributions of the different pathways to radiation doses to humans depend on:

- The type of radionuclide release (atmospheric, aquatic).
- The radionuclide and its chemical composition (half-life, radiation type and energy, environmental mobility and bioavailability).
- The environmental conditions (climate, soil type, season, etc).
- The habits of the exposed population (occupancy, dwelling type, food preferences, use of wild foods, cooking practices, etc.).
- Agricultural practices (plant/ animal breeding, crops, etc.).

Scientific data on environmental radioactivity are collected and regularly reviewed by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). For the development of a radiation protection system for environmental radioactivity, knowledge of the following is needed:

- Nature of radioactive discharges from man-made sources of radiation (radionuclide content and amount, type of release (atmospheric or aquatic).
- Radionuclide level in the environment.
- Methods for assessment of human and biota radiation doses caused by radioactive discharges.
- Data on radiation effects on human health.
- Data on radiological effects on flora and fauna.

According to UNSCEAR, the worldwide mean annual effective radiation dose due to natural radiation is 2.4 mSv with regional variations in the range of 1 – 10

mSv (UNSCEAR, 2000). Environmental radiation can be harmful for both humans and the environmental (Balonov, 2008).

2.4.1 Guidance on radiation protection

The current international system of radiation protection distinguishes between three exposure situations, i.e., planned, emergency and existing exposures. It requires that deterministic human health effects be avoided by almost any means and that possible stochastic health effects are reduced to acceptable levels; this is achieved by limiting public exposure and optimizing radiation protection in planned exposure situations and by optimizing radiation protection through the application of countermeasures in emergency and existing situations. The radiological criteria recommended by the ICRP for planned exposures of the public are an annual dose limit of 1mSv from all controlled sources and appropriate dose constraints from single sources (ICRP, 1991). For emergency and existing situations, some generic reference levels of a verted dose have been recommended by (ICRP 1991, 1993) and more specific guidance has been developed that(IAEA 1996).

Recommendations on the radiation protection of the general public, including those relevant to environmental radiation, are set out in a number of ICRP publications issued during last two decades table (2.5). Among them are ICRP publications 60, in which the foundations of modern radiation protection philosophy are set out (ICRP, 1991). Publications 63, 65, 77, 81, 82 and 96 in which the protection of the public against various sources of environmental radiation is addressed, and several publications devoted to monitoring, assessment and dosimetry (Publications 43, 56, 66, etc.). Most recently, in ICRP publication 91 a framework for assessing the impact of radiation non-human species is established (Balonov, 2008).

Table (2.5): ICRP recommendation on protection against environmental radioactivity

Publication No	Publication Title
60,103	Basic radiation protection recommendation
43, 56, 66, 67, 69, 72, 74, 88, 89, 95, 100	Monitoring, assessment and dosimetry
63	Protection of the public in a radiological emergency
65	Protection against ^{222}Rn
77, 81	Protection at disposal of radioactivity waste
82	Protection of the public in situations of prolonged radiation exposure.
91	Assessing the impact of ionizing radiation on nonhuman species
96	Protection in the event of a radiological attack
101	Optimization of protection and representative individual

2.5 Exposure radiation

The assessment of gamma radiation dose from natural sources is of particular importance because natural radiation is the largest contributor to the external dose of the world population. These dose rates vary from place to place depending upon the concentration of natural radionuclides like ^{226}Ra, ^{226}Th and their progeny and the activity of singly occurring radionuclides like ^{40}K in soil, sediment and rocks. The activity of natural radionuclides in soil and sediment depends mainly on the types of rocks from which they originate. These radionuclides pose exposure risks externally due to their gamma-ray emissions and internally due to radon and its progeny that emit alpha particles. Soil, sediment and rocks such as granite gneisses, limestone, dolomite and quartzite, from environment are widely used as building materials (Narayana et .al., 2007).

The main objective of measuring radioactivity is to make an estimate of radiation dose likely to be delivered externally to the general public. Exposure to radiation can be defined in terms of many parameters. (Al-Hamarneh and Awadallah, 2009).

2.5.1 Absorbed dose rate in air (D)

The contribution of natural radionuclides to the absorbed dose rate in air (D) depends on the natural specific activity concentration of ^{238}U, ^{232}Th and ^{40}K. The greatest part of the gamma radiation comes from terrestrial radionuclides. There is a direct connection between terrestrial gamma radiation and radionuclide concentrations. If a radionuclide activity is known, then its exposure dose rate in air at 1 m above the ground can be calculated using the formula proposed by (Beck 1972) and(UNSCEAR 1988).

$$(D\ nGy/h) = 0.427A_{U\text{-}238} + 0.662A_{Th\text{-}232} + 0.0432A_{k\text{-}40} \quad (2.8)$$

Where: $A_{U\text{-}238}$, $A_{Th\text{-}232}$ and $A_{k\text{-}40}$ are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively, in the samples. The conversion factors of ^{238}U, ^{232}Th and ^{40}K are 0.427, 0.662 and 0.0432 $nGyh^{-1}$ per $BqKg^{-1}$, respectively (Kurnaz et. al., 2007; Al-Hamarneh and Awadallah, 2009). According to (UNSCEAR 2000) report, the dose rate in air outdoor from terrestrial gamma-rays in normal circumstances is about 57 nGy/h, while the worldwide average annual effective dose is approximately 70μSv.

2.5.2 External and internal hazard indices

External and internal hazard indices are calculate from investigate samples. The prime objective of these indices is to limit the radiation dose to permissible dose equivalent limit of 1mSv/y (ICRP 60, 1990). The external hazard index (H_{ex}) is given by model proposed by(Krieger 1981) as:

$$H_{ex} = \frac{A_{R-226}}{370} + \frac{A_{Th-232}}{259} + \frac{A_{K-40}}{4810} \quad (2.9)$$

H_{ex} must not exceed the limit of unity for the radiation hazard to be negligible (Al-Hamarneh and Awadallah, 2009; Kurnaz et. al., 2007). On the other hand, the internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and its short-lived progeny and is given by the following formula proposed by (Beretka and Mathew, 1985) as:

$$H_{in} = \frac{A_{R-226}}{185} + \frac{A_{Th-232}}{259} + \frac{A_{K-40}}{4810} \qquad (2.10)$$

The values of H_{in} must also be less than unity to have negligible hazardous effects of radon and its short-lived progeny to the respiratory organs (Al-Hamarneh and Awadallah, 2009).

2.5.3 Annual effective dose equivalent (E)

In order to make an estimate for the annual effective dose equivalent (E) to be received by the public, the following formula proposed by (Beck 1972) and (UNSCEAR 1988) was used:

$$E\ (\mu Sv/y) = D\ (nGy/h) \times 24h \times 365\text{-}25d \times 0.2 \times 0.7Sv/Gy \times 10^{-3} \qquad (2.11)$$

Where: 0.2 is the outdoor occupancy factor adopted by the UNSCEAR report (2000) and 0.7Sv/Gy is the conversion coefficient from gamma absorbed dose rate in air outdoors D, defined as given in equation (2.8), to effective dose received by adults. (Al.Hamarneh and Awadallah 2009; Kuranz et. al., 2007).

2.6 Radiation dose limits

Dose limits are need as part of the control of human exposure to ionizing radiation. The (ICRP 1991 and 2007) recommended limits of effective doses for both occupational and public exposure due to estimations of fatal and non-fatal cancer risk and hereditary defects. These factors lead to a recommended limit for occupational exposure of 20 mSv per year averaged over a period of 5 years, with no more than 50 mSv per year in a single year. The ICRP also recommended that public exposure should be limited to 1.0 mSv per year, with

exception so long as the average over 5 years doses not exceed 1.0 mSv. A restriction of 2 mSv to surface of the women's abdomen during pregnancy is recommended. The recommended limits are summarized in table (2.6):

Table (2.6): The recommended dose limits (ICRP, 1991)

Application	**Dose limit**	
Effective dose	Occupational	Public
Annual equivalent dose in	20 mSv/year averaged over period of 5 years	1 mSv/ year
The lens of the eye	150 mSv	15 mSv
The skin	500 mSv	50 mSv
The hands and feet	500 mSv	50 mSv

2.7 Previous studies

Over the past several years, some results have been reported of measured activity concentrations of environmental samples collected from various locations in world. Radioactivity levels in some place in world have been documented in previously published papers for soil, rock samples, and plants.

In Sudan, study of natural radioactivity was made in Uro and Kurun (eastern Nuba Mountains) in South Kordofan State to compare the natural radioactivity level of phosphate deposits at Uro and Kurun (Sam and Holm,1995). Assess human radiation exposure and the possible environmental impacts that could be expected from the direct application of phosphates as fertilizes for agricultural land. Soil samples were collected near the root zones of crop plants from different locations. Rock phosphate samples were randomly collected. The alpha spectrometry of the electroplated discs was carried out with silicon ion implanted detectors, for ^{238}U, ^{232}Th, and ^{210}Po. ^{226}Ra and ^{40}K activities were measured using a microcomputer-based low-level γ-ray spectrometry system equipped with a high purity germanium detector (HPGe).The study results showed that^{238}U and its decay products primarily contribute natural radioactivity

of phosphate deposits at Uro and Kurun. ^{232}Th and ^{235}U occur in small concentrations; hence their contribution to natural radioactivity in ore matrix is relatively low. The activity concentration of 2600 Bq/kg natural ^{238}U.The external radiation exposure from the natural radionuclides contained in Uro and Kurun ground rock phosphates show small, result in additional external radiation exposure for members of the population of $5.42x\ 10^{-9}$ nGy/h and $1.13x10^{-9}$ nGy/h for Uro and Kurun rock phosphate, respectively. The study recommended the need further radiological assessment of communities living in the vicinity of Uro and Kurun phosphate deposits, where the assessment should incorporate factors implied by using underground water supplies and by the use of rocks from these areas for house constructions.

A study of the activity concentration of ^{226}Ra in soil and plant samples was measured though out Western Sudan (Sam and Eriksson, 1995). Assess in a natural setting the soil/plant transport of this naturally occurring radionuclide. Plant and soil samples were randomly collected from many farms in six different districts within the study area with large and important food production for the population in Western Sudan (Kordofan and Darfur states) Microcomputer based low- level gamma-ray spectrometry system equipped with a high germanium detector (HPGe) are used. Activity concentration of ^{226}Ra in soil and plant samples was measured. In farm soil analyzed the total activity concentration ranged from 14.4 – 79.1 Bq/kg and the exchangeable fration constituted 7.1 – 27.8%of the total radium content .In the plants analyzed , concentration level ranged from 0.7- 23Bq/kg and 0.1 – 7.6 Bq/kg dry weight for vegetative and edible crop parts, respectively. The results showed: Considerable variation with respect to most soil conditions and the variety of cultivated crops. The soil conditions, content of exchangeable radium, calcium and the clay content have exerted a complex influence on the transfer of radium to plant. There is existence of a tendency for a lower transfer of radium to edible plants than to the vegetative part. The study suggested the use of okra and

pursaline as an indicator plants for radium uptake studies under climatic conditions.

Worldwide, study of determined the concentrations of ^{40}K, ^{226}Ra, ^{238}U and ^{232}Th in surface soil, measured the terrestrial gamma radiation and its contribution to the annual effective dose equivalent to the population in Jordan (Hamarrneh, and Awadallah,2009).A total of 220 surface soils, from the sampling locations of the study areas at 5 cm depth were collected using a stainless steel sampler. The gamma-ray spectrometry system used to carry out the measurements was based on a high-purity germanium (HPGe).The total average concentrations of radionuclides ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K were 42.5, 49.9, 26.7 and 291.1 Bq/kg, respectively. The total average absorbed dose rate in the study areas is found to be 51.5 nGy/h, whereas the annual effective dose equivalent has an average value of 63.2 μSv/y the study showed that radiation hazard parameters associated with the investigated soils do not exceed the permissible limits expect for soils originated from phosphate. Moreover, the radio-elemental concentrations of uranium, thorium and potassium, evaluated for the various geological features in the study areas were calculated to indicate whether relative depletion/enrichment of radio isotopes had occurred. The study recommended Further investigation is still needed both to measure soils from deep layers and vegetation grown by these soils.

Measurement of environmental radioactivity for estimation of radiation exposure from saline soil of Lahore, has been studied to measure the amount of radioactivity (Akhter et .al., 2003). Assessment of radiation dose from the saline soil of Lahore area. The area was divided into 25 sites the distance between every points was about 15-17m from every site. 5 samples were taken at a step of 5 cm depth covering 25 cm depth; the total number of samples was 125. The technique of gamma-ray spectrometry was applied for the determination of radioactivity of the samples under investigation. The spectrometry system consisted of a high purity germanium (HPGe) detector. Activity concentration of

the concerned radionuclides were as: ^{40}K, 524.84 – 601.62 Bq/kg,^{137}Cs not detected, ^{226}Ra, 24.73 – 28.17 Bq/kg, and ^{232}Th, 45.46 – 52.61 Bq/kg.The study results revealed that: The soil of barren area show different amount of radioactivity when compared with that of the cultivated soil. The activity levels were found to follow normal distribution. The distribution of activity with respect to depth is concerned. No relation has been observed between these two quantities.

Study was conducted to assess of natural radioactivity level of bituminous soil in Agbabu, south west Nigeria has been studied using gamma- spectrometry based on high- purity (Isinkaye, 2008). Determined the concentrations of the naturally occurring radionuclides and estimated the radiological hazards associated with the natural radioactivity levels of the area. Twenty samples were collected in all, which consist of 19 bituminous soil samples and one viscous bitumen sample. The soil samples were collect randomly from different sampling points spread over Agbabu land area at a depth of about 5 - 20 cm horizon. The γ-ray spectrometry used to carry out the measurements was based on a high- purity germanium (HPGe).The mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th, respectively in the bituminous are 65.75±6.50, 9.83±2.83, and 8.64±2.60 Bq/kg. The conversion factors used to obtain the absorbed dose rate in air at a height of 1m above the ground level from the different sampling points ranged from 4.34±1.18 nGy/h to 25.31±5.90 nGy/h. The annual outdoor effective dose to which humans are exposed in this environment ranged from 10 to 30 μSv/y. The radium equivalent values obtained in this study ranged from 9.7 to 54.4 Bq/kg. The results of this study indicated that the area of low background radiation levels as such no significant radiological hazard is expected in the area.

Evaluation of radionuclides activity concentrations and environmental outdoor gamma dose rate in Kirklareli, Turkey (Taskin, 2009).230 soil samples were collected from 177 locations. Soil samples were analyzed by gamma spectrometry. The average ^{226}Ra, ^{238}U, ^{232}Th, ^{137}Cs, and^{40}K activities were

37±18 Bq/kg, 28±13 Bq/kg, 40±18 Bq/kg, 8±5 Bq/kg, and 667±218 Bq/kg, respectively. The outdoor gamma dose rate was determined by Eber line smart portable device (ESP-2) and measurements were taken in air for two minutes at 1m from the ground. The average outdoor gamma rate was 118±43 nGy/h and annual

Effective gamma dose of Kirklareli was 144μSv/y. The study results revealed that; the level of gamma radiation was directly associated with the activity concentrations of radionuclides in the soil samples and cosmic rays. Radionuclide activity concentrations of samples varied within the study area due to the differences of geological structures. The maps determined by GPS indicated that gamma dose rates were highly correlated with ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K activity concentrations.

Study of natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ- ray spectrometry (Rani and Singh, 2005).The measured activity in soil ranges from 42.09 to 79.63 Bq/kg, 52.83 to 105.81Bq/kg and 95.33 to 160.30 Bq/kg for ^{226}Ra, ^{232}Th, ^{40}K, with the mean values of 57.34, 82.22, and 135.75 Bq/kg, respectively. The average outdoor terrestrial gamma air absorbed dose rate was 83.38 nGy/h. The study yields an annual effective dose in range of 0.07- 0.13mSv/y. The high values of radionuclides in some of the soil samples may be correlated with the uranium mineralization or the presence of the geological line aments/ faults in the area.

Natural radioactivity in some major rivers of coastal Karnataka on the south west coast of India to assess the radiological hazard of natural radioactivity in the samples (Narayana et .al., 2007).Soil, sediment and rock samples were collected from three major rivers of coastal Kamataka. The activity concentrations of natural radionuclides in samples were determined using Nal (Tl) gamma-ray spectrometer. In Kali, Sharaavathi, and Netravathi the median values of absorbed gamma dose rates in air were found to be 44 nGy/h, 35 nGy/h, and 57 nGy/h, respectively. The activity concentrations were found to be

2.9 Bq/kg for ^{40}K, 1.0 Bq/kg for^{226}Ra, and 0.6 Bq/kg for ^{232}Th. The study results revealed that the higher activity of natural radionuclides in sediment samples because of the release of monazite – bearing minerals due to the weathering of rocks in catchment areas. The variations of natural radioactivity at different sampling stations are due to the variations of specific minerals, rare earth element and local geological conditions. A comparison of median activities of ^{226}Ra, ^{232}Th and ^{40}K indicates that ^{40}K is the dominant gamma emitting source in the soil.

Comparative study of natural radioactivity levels in soil samples from the upper Siwalik and Punjab, India using gamma ray spectrometry (Singh et. al., 2009). Investigates the activity concentration of radioactive elements determined gamma ray absorbed dose in soil samples. Soil samples collected from different locations of study area. Using HPGe detector based on high resolution gamma spectrometry system. The concentration of natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in soil varies from 28.3±0.5 to 81.0±1.7 Bq/kg, 61.2±1.3 to 140.3±2.6 Bq/kg, and 363.4±4.9 to 1002.2±11.2 Bq/kg respectively. The total absorbed dose rate calculated from activity concentration of ^{226}Ra, ^{232}Th, ^{40}K, ranged from 71.1to 162.0 nGy/h. The radium equivalents (R_{eq}) and the external hazard index (H_{ex}) which resulted from the natural radionuclides in soil were also calculated and found to vary from 149.4 to 315.8 Bq/kg and from 0.40 to 0.95 respectively. The average values of activity concentration of radionuclides around Upper Siwaliks were be higher than the corresponding values from adjoining areas. This may be due to the abundance of high activity fossil. Bones at some localities of Upper Siwaliks. There was correlation between the activity of radionuclides and soil samples.

Radioactivity concentration and dose assessment for soil samples around Adana, Turkey were measured to determined natural radionuclide activity concentrations in soil samples, and evaluated the annual effective dose (Degerlier et. al., 2008).Soil samples were taken with 25 cm diameter, cores

collected at 38 different locations at different depths ranging from 0 to 30 cm. these samples were taken from uncultivated field and sampling stations were chosen close to populated areas. Gammas spectroscopic were performed using a coaxial HPGe detector. The average activity concentrations of ^{238}U, ^{232}Th, and ^{40}Kwere found to be 17.6, 21.1, and 297.5 Bq/kg respectively. Outdoor gamma dose measurements in air 1m above ground level were determined by using portable gamma scintillation detector. Average outdoor gamma rates in sample stations were determined as 67 nGy/h. The annual effective dose to public was found to be 82 µSv/y. The study results indicated that: The activity concentrations vary depending on the geological and geographical conditions of different regions. The most important reason for the higher activity concentrations with respect to the others in some regions is a higher uranium and thorium content in rock and soil structure in these regions.

Study of concentrations of ^{210}Po and ^{210}Pb in soil and vegetable in Kucuk Menderes basin of Turkey (Ekdal et.al., 2006).To determine ^{210}Pb and ^{210}Po activity concentrations in order to assess any excess ^{210}Pb and ^{210}Po concentrations due to the fertilization. The activity concentrations in vegetables were detected between0.15- 9.40 Bq/kg and 0.23- 0.62 Bq/kg for ^{210}Po and ^{210}Pb, respectively. In the bulk soil cores samples from phosphate fertilizer applied agricultural lands the ranges for activity concentrations of ^{210}Po and ^{210}Pb were 30.10 – 47.15 Bq/kg and 31.27 – 61.53 Bq/kg, respectively. The annual effective dose equivalents to man from ^{210}Po and ^{210}Pb due to consumption of leafy vegetables are calculated to be 30.51and 22.73µSv/y respectively. Likewise root vegetables give dose equivalent of 22.89µSv/y from ^{210}Po and 44.77µSv/y from ^{210}Pb.The study results revealed that ^{210}Po and ^{210}Pb radionuclide concentrations are much higher in associated soils of vegetables than vegetables itself. Concentrations of radionuclides in cultivated sites do not show so much difference between the sites since all fields are in the same area. Low activity concentrations of ^{210}Po and ^{210}Pb measured in root vegetables may

be due to the fact that they can mainly take up the radionuclides directly from associated soil without any considerable contribution from the atmosphere. The maximum dose arising from the consumption of ^{210}Po and ^{210}Pb through foodstuffs including vegetables.

Study on the radiation level and distribution of some naturally occurring radioactive materials (NORM) in the soils of the coastal areas of Nigeria (Alatise et. al., 2008). To determine the concentrations of radionuclides in the soil samples. These soil samples were analyzed using a high resolution, low background, hyper-pure coaxial gamma-ray detector (HPGe).The activity of^{40}Kranges between111.9 and 444.7 kBq/kg with a median value of 283.28 kBq/kg, the activity of ^{226}Ra varies from 23.24 to 43.66 kBq/kg with a median value of 34.54 kBq/kg, and activity of ^{232}Th ranges from 6.45 to 12.79 kBq/kg with a median value of 9.17 kBq/kg. The mean absorbed dose rate in air due these NORM was found to be 33.655±3.409 nGy/h. The radioactivity concentration of ^{40}K in these coastal areas was much higher than those of the other naturally occurring radionuclides. ^{40}K made the largest contribution to radionuclides content of soils around these areas; this is likely due to the fact that it is not naturally abundant in the environment.

CHAPTER THREE

3. MATERIAL AND METHOD

3.1 The study area

Area under study is located in the South Kordofan State. The state is bounded approximately coordinates: Latitudes 29º.32\ and 31º.49\ E, and longitudes 11º.47\ and 12º.08\ N, as depicted in Fig (3.1)

3.2 Geological information of Nuba mountains

The Nuba Mountains region comprises an inlier of Basement complex rocks surrounded by a cover of younger, unfolded sediments. Quartzo-feldspathic gneisses and migmatites, a Metasedimentary unit, and an assemblage of basic volcanics, sediments and ultramafic rocks are all intruded by syn- to late-organic batholithic granitoids. Anorogenic alkali syenite ring-complexes pierce the Basement units. Many of the latter are fault bounded, with at least two major N-S thrusts separating gneisses, metasediments and metavolcanic. see Fig (3.1) (Abdelati and Vial 1986)

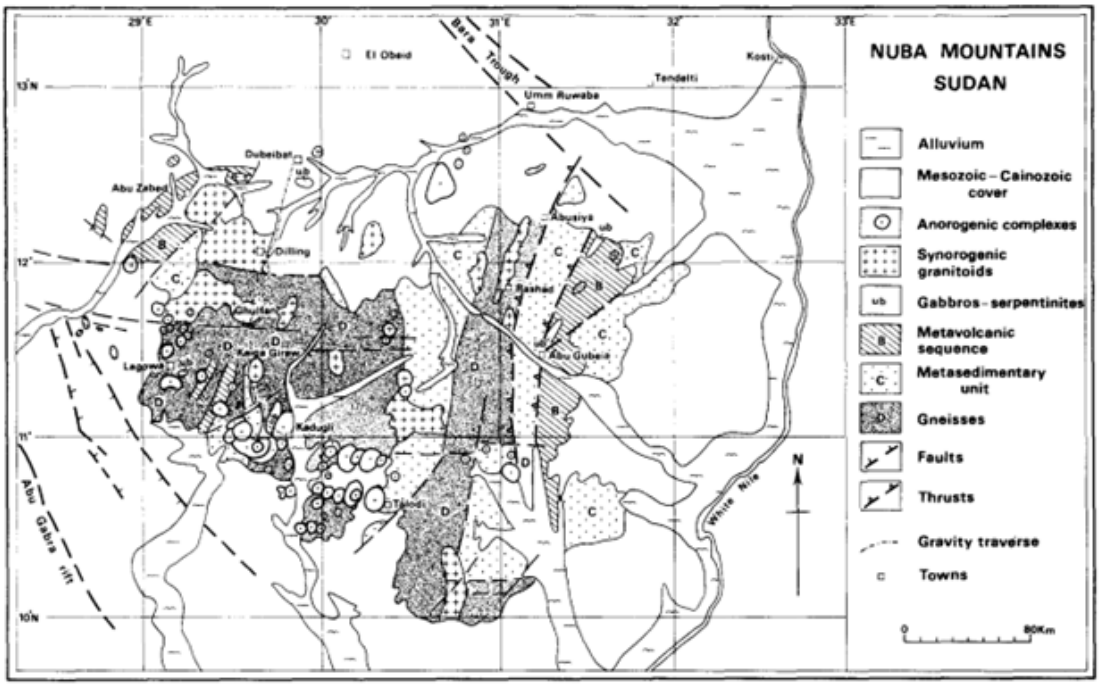

Fig. (3.1) Geological map of Nuba Mountains.

3.3 Sample collection and preparation

A total of 102 soil, rock and crops samples were collected from various sites. A survey was designed to determine the concentration of ^{238}U, ^{232}Th, ^{40}K and others related elements such as ferrum (Fe) and antimony (Sr), etc… from area of interest in the district Dalling at the northern and eastern parts of South Kordofan State (Uro and Kurn), see Fig (3.2). These areas were selected due to extremely high background radiation relative to other areas of the South Kordofan State. 69 samples of soil, 22 samples of rock and 11 samples of crops were collected from different locations through the study area. The names of sampling locations with their respective co-ordinates are presented in tables (3.1) and (3.2), and absorbed dose rates in air at 1 m height (nGy/h) were measured by Radose and annual effective dose (μSv/y) as derived using UNSCEAR DRCFs; see tables (3.3) and (3.4).

3.3.1 Soil samples

At each sampling point, grass and tree leaves removed from the top of the soil surface before the soil was collected. Three cores of the top soil were taken in depth of at 15cm, by using stainless steel sampler, coordinating were recorded using GPS.

All samples were sun dried on aluminum trays, then crushed and ground to a fine powder a grinding mill. The sample sizes were homogenized by passing through a 2mm test sieve then the samples were mixed to obtain a representative sample weight 500gm. Samples were sealed in a 500 ml Marinelli beakers and left more than one month to reach secular equilibrium.

3.3.2 Rock samples

A total 22 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 in a 500 ml Marinelli beakers

and left for more than a month before counting by gamma- ray spectroscopy to allow secular equilibrium.

3.3.3 Crops samples

A total of 11 samples of crops from different random locations around the sampling site were collected, samples were cleaned, air dried for one week, placed in an over at 60^{o}c for 6 hours, samples crushed and homogenized by passing through 2mm test sieve, the dry weights were determined, and samples were stored in a 500 ml Marinelli beakers to reach secular equilibrium.

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

sample code	Location	GPS reading		
		Lat. ^{o}E	Long. ^{o}N	Alto. Ft
S1	Katla	29.32740	11.77061	714
S2	Katla	29.31679	11.76059	711
S3	Katla	29.31524	11.75661	696
S4	Walaey	29.36329	11.83881	704
S5	Walaey	29.32512	11.86663	661
S6	Walaey	29.35922	11.83814	704
S7	Kogoriea	29.36595	12.01974	708
S8	Kogoriea	29.36970	12.02592	705
S9	Kogoriea	29.37340	12.03601	697
S10	El karko	29.39071	12.06645	701
S11	El karko	29.404550	12.08214	692
S12	El karko	29.39369	12.05769	714
S13	El funda	29.42169	12.03956	749
S14	El funda	29.423442	12.03436	761

S15	El funda	29.43074	12.03514	776
S16	El netil	29.58293	12.00354	728
S17	El netil	29.57723	12.00299	731
S18	El netil	29.56323	12.00057	749
S19	Sallara	29.51424	11.93260	756
S20	Sallara	29.50505	11.95949	787
S21	Sallara	29.49256	11.95492	808
S22	Hajer el sultan	29.53980	11.96468	766
S23	Hajer el sultan	29.54604	11.94126	742
S24	Hajer el sultan	29.54508	11.95297	758
S25	El fous	29.56533	11.94317	734
S26	El fous	29.56704	11.95100	742
S27	El fous	29.56038	11.96983	752
S28	Kakara	29.56917	11.97653	729
S29	Kakara	29.57912	11.97427	740
S30	Kakara	29.567311	11.98005	744
S31	Kelara	29.51922	12.00807	747
S32	Kelara	29.51501	12.01102	796
S33	Kelara	29.50607	12.00952	807
S34	Tondiya	29.48577	12.01947	808
S35	Tondiya	29.46553	12.00441	807
S36	Tondiya	29.44955	11.99982	789
S37	Gelogical camp	31.40768	11.69785	643
S38	Uro east	31.4072267	11.70151	646
S39	Uro west	31.40901	11.70275	645
S40	Uro market	31.40901	11.70275	645
S41	Uro middle	31.40740	11.70877	643
S42	Dar el salam school	31.41085	11.61756	645

S43	Um takatik	31.45689	11.59217	621
S44	Um takatik	31.47895	11.59217	613
S45	Um takatik	31.49083	11.55859	579
S46	Um takatik(Termites)	31.49083	11.55859	579
S47	Kurun	31.49551	11.82201	562
S48	Kurun hill	31.42852	11.51716	580
S49	Kurun	31.40862	11.49673	570
S50	Kurun	31.39903	11.49206	582
S51	Abu galaha	31.45259	11.47219	533
S52	Tumluk hill	31.43319	11.63838	631
S53	Tumluk hill	31.432979	11.63746	653
S54	Tumluk	31.43196	11.63584	636
S55	Aryab camp	31.43465	11.64110	629
S56	Aryab (trench)	31.46130	11.62022	636
S57	Aryab	31.46311	11.61937	618
S58	Uro hill height	31.41040	11.71259	648
S59	Near Uro village	31.41009	11.71132	651
S60	Near Uro hill	31.41086	11.71129	650
S61	Uro village	31.40767	11.71223	652
S62	Uro village	31.40997	11.71479	655
S63	Tirmi stream	31.41552	11.73473	647
S64	Stream between Tirmi and Uro	31.41517	11.73164	622
S65	Western north of Uro	31.41250	11.72360	637
S66	El layoon farm	31.41879	11.67551	630
S67	El layoon village	31.35570	11.71649	668
S68	El layoon	31.31840	11.7370	704
S69	El layoon	31.42905	11.67912	625

Table (3.2): Location names with their coordinates in rock samples

sample code	Location	GPS reading		
		Lat. °E	Long. °N	Altt. Ft
R70	Katla	29.32740	11.77061	714
R71	Walaey	29.32512	11.86663	661
R72	Kogoriea	29.36970	12.02592	705
R73	El karko	29.39071	12.06645	701
R74	EL funda	29.43047	12.03514	776
R75	El netil	29.56323	12.00057	749
R76	Sallara	29.50505	12.95949	787
R77	Hajer el sultan	29.54508	11.95927	758
R78	El fous	29.56038	11.96983	752
R79	Kakara	29.567311	11.98005	744
R80	Kelara	29.51922	12.00807	747
R81	Tondiya	29.48577	12.01947	808
R82	Um takatik hill	31.4689	11.61756	629
R83	Kurun hill	31.42683	11.52641	615
R84	Kurun hill	31.42681	11.52641	615
R85	Beside kurun hill	31.39860	11.49413	591
R86	Beside kurun hill	31.39860	11.49413	591
R87	Tumluk	31.43319	11.63638	631
R88	Aryab	31.46130	11.62022	636
R89	Uro hill	31.41040	11.71259	648
R90	Tirmi hill	31.41552	11.73473	647
R91	Uro market hill	31.40740	11.70275	645

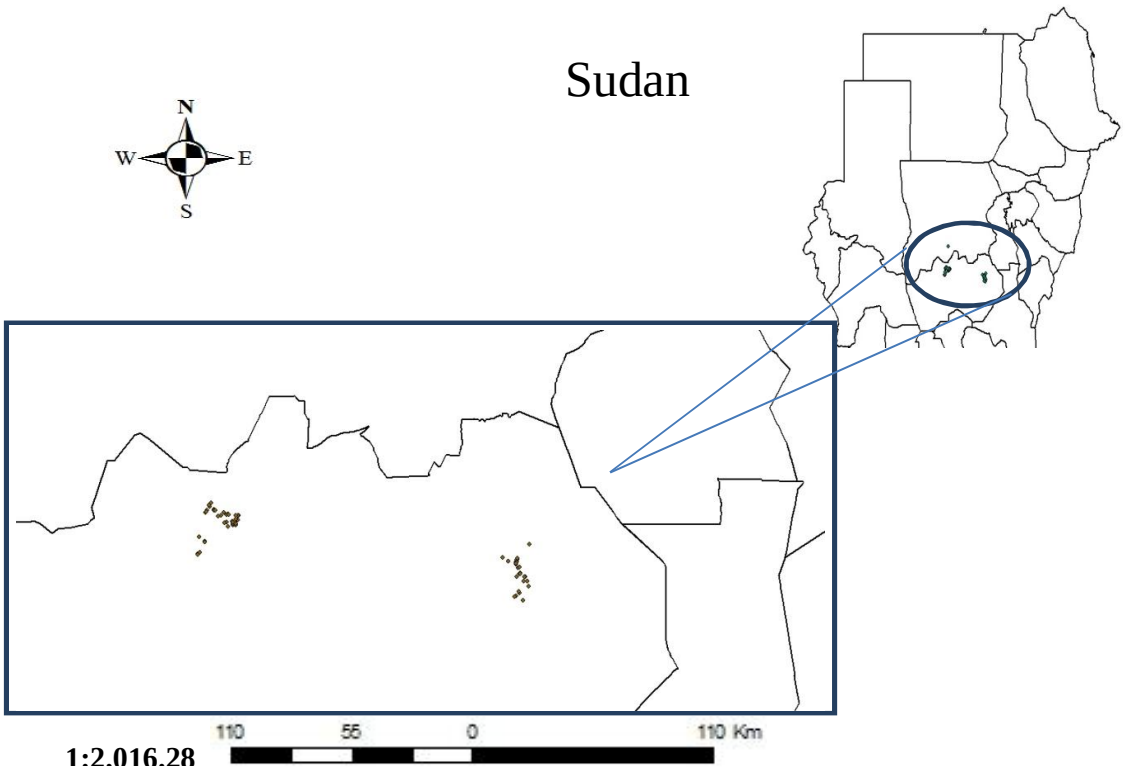

Fig. (3.2): Sampling location(South Kordofan State)

Table (3.3): Absorbed dose rates in air at 1 m height (nGy/h) were measured by Radose and annual effective dose (µSv/y) as derived using UNSCEAR DRCFs in soil samples

Sample code	**CPS**	**Dose rate (nGy/h)**	**Ann. Eff. Dose (µSv/y)**
S1	21.00	0.22	0.27
S2	139.00	0.17	0.21
S3	119.70	0.13	0.16
S4	174.30	0.22	0.27
S5	123.00	0.15	0.18
S6	174.00	0.36	0.44
S7	126.70	0.23	0.28

S8	133.30	0.22	0.27
S9	101.70	0.15	0.18
S10	119.00	0.22	0.27
S11	68.10	0.10	0.12
S12	98.50	0.12	0.15
S13	66.30	0.22	0.27
S14	63.20	0.15	0.18
S15	66.70	0.10	0.12
S16	61.90	0.09	0.11
S17	59.30	0.07	0.09
S18	55.00	0.10	0.12
S19	81.40	0.14	0.17
S20	82.20	0.08	0.10
S21	88.10	0.15	0.18
S22	63.50	0.11	0.13
S23	54.90	0.08	0.10
S24	74.10	0.08	0.10
S25	73.50	0.17	0.21
S26	77.80	0.09	0.11
S27	78.30	0.11	0.13
S28	94.90	0.09	0.11
S29	86.30	0.07	0.09
S30	87.70	0.10	0.12
S31	68.90	0.11	0.13
S32	60.80	0.11	0.13
S33	62.60	0.03	0.04
S34	85.50	0.19	0.23
S35	54.70	0.07	0.09

S36	57.70	0.10	0.12
S37	26.30	0.13	0.16
S38	44.40	0.11	0.13
S39	506.70	0.43	0.53
S40	59.10	0.18	0.22
S41	62.65	0.25	0.31
S42	74.40	0.14	0.17
S43	65.70	0.34	0.42
S44	28.70	0.10	0.12
S45	14.20	0.14	0.17
S46	16.80	0.05	0.06
S47	22.40	0.10	0.12
S48	91.30	0.08	0.10
S49	44.90	0.16	0.20
S50	114.00	0.12	0.15
S51	25.70	0.18	0.22
S52	31.00	0.70	0.86
S53	35.40	0.16	0.20
S54	28.60	0.09	0.11
S55	30.70	0.10	0.12
S56	21.00	0.60	0.74
S57	30.50	0.15	0.18
S58	329.00	0.50	0.61
S59	130.00	0.26	0.32
S60	106.70	0.18	0.22
S61	119.00	0.20	0.25
S62	376.30	0.61	0.75
S63	48.70	0.11	0.13

S64	64.50	0.14	0.17
S65	75.50	0.14	0.17
S66	21.20	0.08	0.10
S67	18.70	0.08	0.10
S68	16.40	0.08	0.10
S69	20.50	0.08	0.10

Table (3.4): Absorbed dose rates in air at 1 m height (nGy/h) were measured by Radose and annual effective dose (µSv/y) as derived using UNSCEAR DRCFs in rock samples

Sample code	**CPS**	**Dose Rate (nGy/h)**	**Ann. Eff. Dose (µSv/y)**
R70	139.00	0.17	0.208631
R71	174.00	0.36	0.441806
R73	133.30	0.66	0.809978
R74	119.00	0.22	0.269993
R75	66.70	0.10	0.122724
R76	59.30	0.10	0.122724
R77	88.10	0.15	0.184086
R78	74.10	0.07	0.085907
R79	78.30	0.11	0.134996
R80	94.90	0.11	0.134996
R81	68.90	0.11	0.134996
R82	85.50	0.19	0.233176

3.4 Gamma-ray spectroscopy

The gamma spectroscopy system which used consists of a detector, electronics to collect and process the signals produced by the detector, and a computer with processing software to generate, display, and store the spectrum. Other components, such as rate meters and peak position stabilizers, may also be

included. In this study gamma-spectrometry based on high efficiency NaI (Tl) detector.

Gamma spectroscopy detectors are passive materials that wait for a gamma interaction to occur in the detector volume. The most important interaction mechanisms are the photoelectric effect, the Compton Effect, and pair production. The photoelectric effect is preferred, as it absorbs all of the energy of the incident gamma ray. Full energy absorption is also possible when a series of these interaction mechanisms take place within the detector volume. When a gamma ray undergoes a Compton interaction or pair production, and a portion of the energy escapes from the detector volume without being absorbed, the background rate in the spectrum is increased by one count. This count will appear in a channel below the channel that corresponds to the full energy of the gamma ray. Larger detector volumes reduce this effect.

The voltage pulse produced by the detector (or by the photomultiplier in a scintillation detector) is shaped by a multichannel analyzer (MCA). The multichannel analyzer takes the very small voltage signal produced by the detector, reshapes it into a Gaussian or trapezoidal shape, and converts that signal into a digital signal. In some systems, the analog-to-digital conversion is performed before the peak is reshaped. The analog-to-digital converter (ADC) also sorts the pulses by their height. ADCs have specific numbers of "bins" into which the pulses can be sorted; these bins represent the channels in the spectrum. The number of channels can be changed in most modern gamma spectroscopy systems by modifying software or hardware settings. The choice of number of channels depends on the resolution of the system and the energy range being studied. The multichannel analyzer output is sent to a computer, which stores, displays, and analyzes the data. A variety of software packages are available from several manufacturers, and generally include spectrum analysis tools such as energy calibration, peak area and net area calculation, and

resolution calculation. The instrumentation set-up of γ-ray spectroscopy system with NaI (Tl) detector is shown in Fig. (3.3).

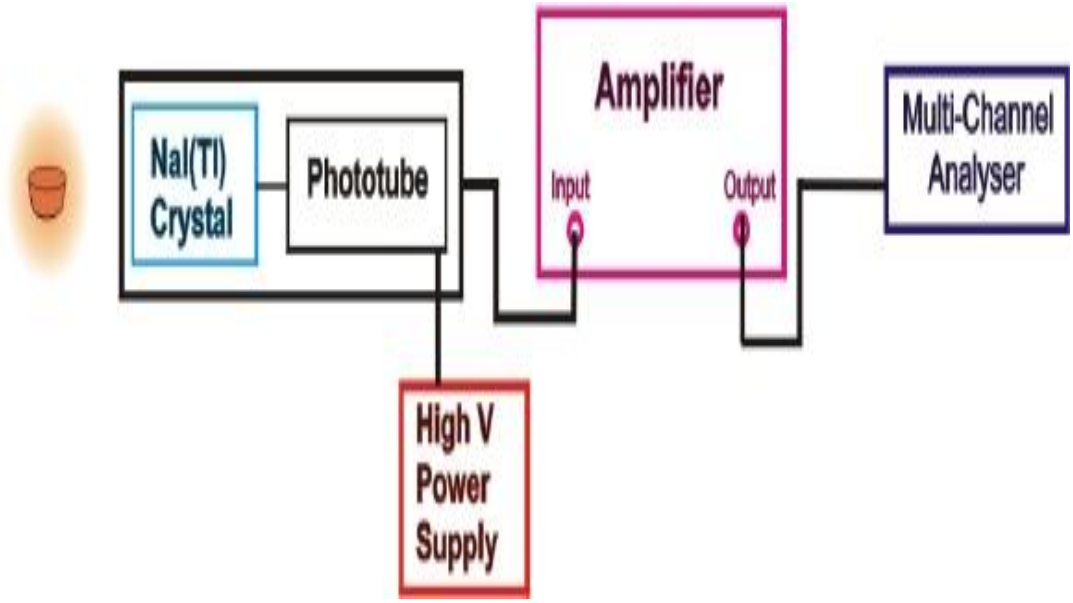

Fig.(3.3): Block diagram of gamma-ray spectrometer

3.4.1 System calibration of gamma

To identify and quantify the concentration of the unknown radionuclides, the system must be calibrated with respect to energy, efficiency and resolution .The resolution measurement is required for identification of peaks in the peak search routine. Energy calibration is necessary for sample qualitative analysis. The efficiency calibration is required for sample quantitative analysis.

3.4.1.1 Energy calibration

When a gamma spectroscopy is used for identifying samples of unknown composition, its energy scale must be calibrated first. Energy calibration was performed by using the peaks of a known source, such as ^{137}Cs or ^{60}Co. Because the channel number is proportional to energy, the channel scale can then be converted to an energy scale. Energy calibration was performed by using mixed radionuclide standard (MW625) obtained from IAEA in form of 500 ml

Marinelli beaker table (3.5). The energy calibration curve obtained is presented in Fig. (3.4).

Table (3.5): Types of mixed radionuclides used for system calibration and their corresponding gamma energies

Radionuclide	**Energy(keV)**
^{241}Am	59.496
^{109}Cd	87.981
^{57}Co	122.144
^{137}Cs	661.706
^{54}Mn	834.883
^{65}Zn	1115.301
^{60}Co	1173.337
^{60}Co	1332.571

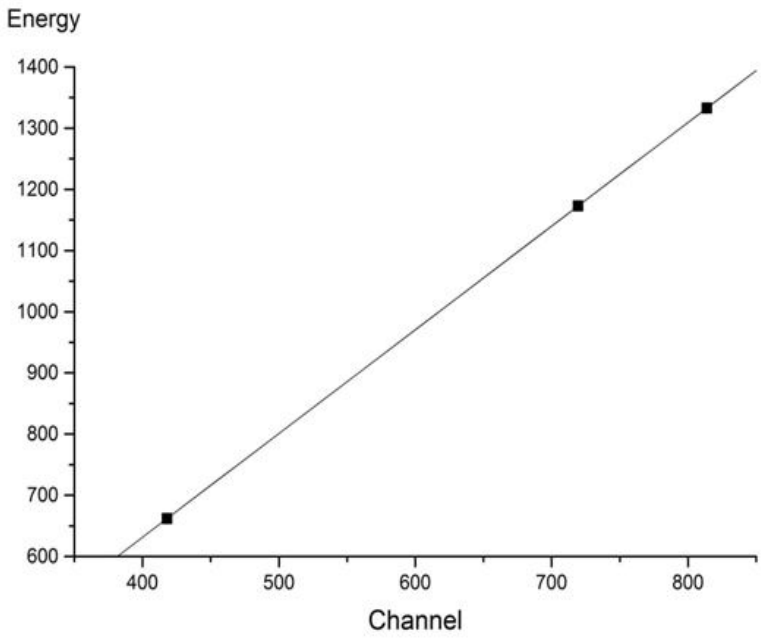

Fig. (3.4): Energy calibration curve

3.4.1.2 Efficiency calibration

The detector efficiency was calibrated using a mixed radionuclide sources (MW625) in 500 ml Marinelli beaker geometry. The container was placed directly on the detector and counted for half-hour. The spectrum was stored in the computer, and analyzed using the software "winTMCA32". The following equation was used to obtain the efficiency of each gamma-line:

$$\eta = \frac{Counts\ (cps)}{I_\gamma\ x\ A\ (Bq/kg)} \qquad (3.1)$$

Where, η is the efficiency of the detector at specific energy I_γ Iγ is gamma intensity, and A is the activity of the standard. The energies, their respective branching ratios and the corresponding efficiency of the radionuclides in thestandard are given in table (3.6) and the efficiency curve obtained was presented in Fig (3.5).

Table (3.6): Types of radionuclides used for efficiency calibration and their corresponding gamma energies

radionuclide	**Energy**	**CPS**	**Activity (Bq)**	Iγ	**Efficiency**
^{137}Cs	662	119.32	2294.01	0.851	0.061
^{60}Co	1173	29.31	1122.985	1	0.026
	1333	26.36	1122.985	1	0.024

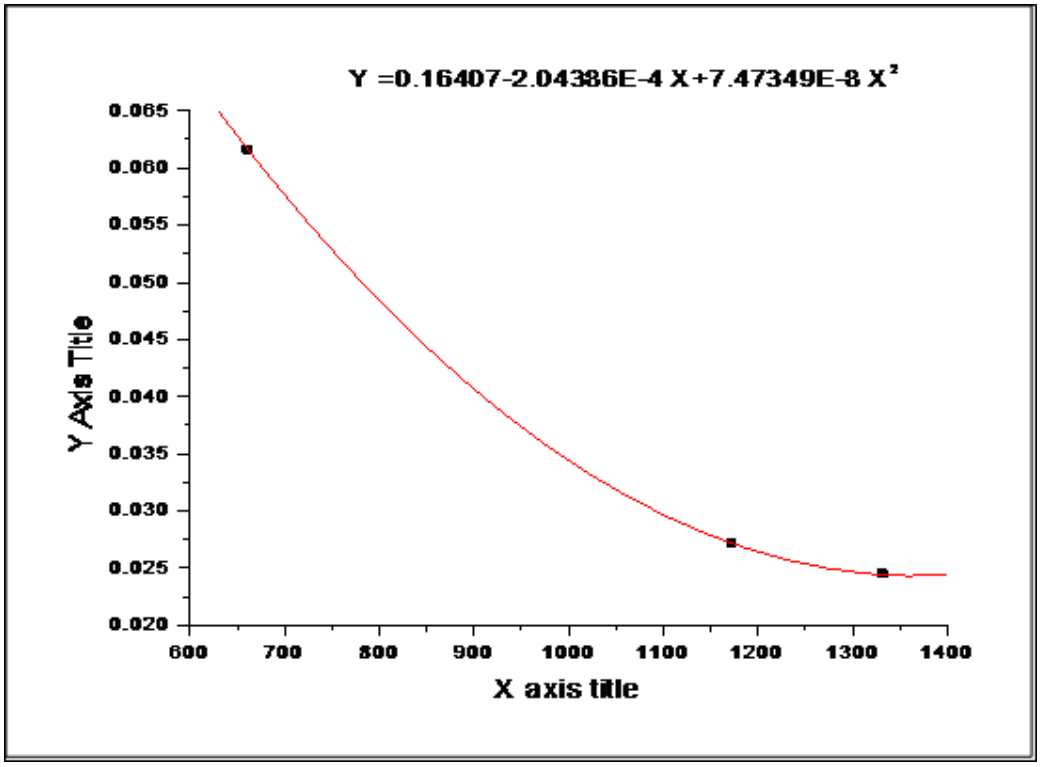

Fig (3.5): Efficiency calibration curve

3.5 Evaluation of the gamma dose rates in air outdoors

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. In this study the absorbed dose rate in air at a height of 1 m above ground surface was calculated from the measured activity concentrations of gamma-emitters using different dose-rate conversion factors; see table (3.7). In principle, if natural radioactive nuclides are uniformly distributed in the ground, dose rates D (nGy/h) at 1 m above the ground surface are calculated by the following formula (Tzortzis et al., 2003):

D = Concentration (Bq/kg) x Conversion factor (nGy h^{-1}/ Bq kg^{-1}) (3.2)

3.6 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 given below.

3.6.1 UNSCEAR

UNSCEAR also has adopted DRCFs assuming a radioactive equilibrium between radionuclides in ^{232}Th, ^{238}U decay series and ^{40}K, homogeneous dry soil density of 1.4 g/cm^3 and the distribution of radionuclide concentration in the first meter of the soil is homogeneous.

3.6.2 K. Saito and P. Jacob (1995)

All dose conversion factors were calculated as usual for a point receptor located 1 m above the ground. In the present decade Monte Carlo techniques have been used almost exclusively in order to calculate absorbed dose rate in air. Chen (1991) developed a Monte Carlo algorithm to track the photon transport equation in the soil/air medium. One of the most complete studies of air kerma rate per unit of soil mass for natural sources uniformly distributed in the ground is performed by (Saito and Jacob ,1995). The photon transport calculations were carried out using the Monte Carlo program YURI (Saito and Cunha, 1997) which has been verified through comparison with various experimental and theoretical data (Clouvas et. al. ,2000).

3.6.3 Monte Carlo codes

(Clouvas et. al. 2000) used different Monte Carlo codes, such as the MCNP code of Los Alamos (1986), the GEANT code of CERN (1993) and a Monte Carlo code (called MC) developed in the Nuclear Technology Laboratory of the Aristotle University of Thessaloniki, Greece. A short description of the Monte Carlo codes and the implementations of the simulations used are given below.

3.6.3.1 The MCNP code

The Los Alamos National Laboratory MCNP code is a general purpose Monte Carlo radiation transport code that can numerically simulate neutron, photon and electron transport. For photons, the code takes account of incoherent and coherent scattering, the possibility of fluorescent emission after photoelectric absorption, absorption in pair production with local emission of annihilation radiation and bremsstrahlung. The user supplied information required by MCNP contains information about specific items such as the geometry and the materials characterizing the environment which will be simulated, the source distribution of the radiation and finally the type of the answers desired (e.g. energy distribution of photon flux in a given position). The geometry of the calculation using the MCNP code is simple. The different components incorporated in the simulation are: Air: Simulated as a cylinder of 40 m radius and 1.5 m height with atomic composition of 79% N and 21% O and a density of 0.00129 g cm^{-3}
Soil: Simulated as a cylinder of 40 m radius and 1 m depth with atomic composition of 7.3% Al, 2.1% C, 1.4% Ca, 3.9% Fe, 0.9% K, 0.5% Mg, 0.1% N, 0.6% Na, 50.1% O, 32.7% Si, 0.4% Ti and a density of 1.3 g cm^{-3}
The radius of 40 m and the soil depth of 1 m are sufficient in order to consider the emission photon geometry as half space geometry. The source distribution of radiation incorporated in the MCNP code is photon emitters uniformly distributed in the soil with 8 different photon energies between 200 and 3000

keV. The number of photons emitted in each of these 8 simulations was fifty million. For the determination of the photon flux energy distribution at one meter above soil two virtual detectors were used:

a. The point detector which is a standard tally of the MCNP code, gives the energy distribution of the photon flux directly, normalized per starting photon
b. A sphere of radius of 40 cm with its center located at 1 m above soil. The MCNP code counts the number of photons as a function of their energy crossing the surface of the sphere and calculates the photon fluence energy distribution, normalized per starting photon, which can be easily transformed into flux per unit activity per unit of soil mass (g cm^{-2} s^{-1} per Bq/kg). Both virtual detectors are located on the Z axis of the cylinder of radius of 40 m. Special detectors were also used in some cases where the deposited energy of photons per unit mass of air is directly computed (Clouvas et. al., 2000).

3.6.3.2 The GEANT code

The GEANT code was developed by the Application Software Group at CERN. The GEANT program describes the passage of elementary particles through matter. The principal applications of the code are:

a. The tracking of particles through an experimental setup for simulation of detector response.
b. The graphical representation of the setup and of the particle trajectories.

The code is used primarily for the simulation "runs" of complex experiments in order to obtain an optimal placement of different detectors and to calculate various efficiencies for the detection of different particles. The code has been used recently for simulation of Ge detectors (Clouvas et .al. 2001).

For photons, the code takes into account the photoelectric effect, Compton scattering and pair production. It also includes electron-positron processes of multiple scattering, ionization, bremsstrahlung, and annihilation.

X-rays and Auger electrons following the photoelectric effect are also considered. The simulation consists of tracking all particles created initially by the user and all secondary ones that are created along their path as a result of the physical processes taken into account. Each particle history, from its generation to full dissipation of its energy, is stored. The geometry of the calculation using the GEANT system is simple and is the same as used for the MCNP code. The atomic composition of the soil and air is the same as used for the MCNP code. The virtual detector is a surface detector (circle of radius 2 m) located 1 m above soil on the Z axis of the cylinder of radius 40 m. As in the MCNP code the source distribution of radiation are photon emitters uniformly distributed in the soil with eight different photon energies between 200 and 3000 keV. The number of photons emitted in each of these 8 simulations was fifty million. The tracing of gamma rays starts at a certain point in the soil and then carried on until the photon disappears or leaves the space considered. The surface detector counts the number of photons crossing the surface as a function of their energy and their angle of incidence. Knowing the number of photons emitted, the area of the surface detector, the number of photons crossing the surface, their corresponding energy and angle of incidence, the photon flux energy distribution per unit activity per unit of soil mass (g cm^{-2} s^{-1} per Bq/kg) can be calculated (Clouvas et.al, 2000).

In this study different Dose Rate Conversion Factors (DRCFs) for different radionuclides are used as deduced by Saito and Jacob (Clouvas et .al,2000) and UNSCEAR 2000 report see table (3.7).

Table (3.7): Conversion factors for different radionuclides as deduced by Kocher and Sjoreen, Beck et al., Saito and Jacob, recent results from various Monte Carlo technique obtained by (Clouvas et. al 2000). and UNSCEAR values in units of nGy h^{-1}/Bq kg^{-1} (Kohshi et.al ,2001)

Nuclide	SAITO	MCNP	GEANT	UNSCEAR
^{238}U Series				
^{214}Pb	0.05460	0.04150	0.04342	
^{214}Bi	0.40100	0.33849	0.35554	
Total	**0.46300**	**0.38092**	**0.39996**	**0.462**
232Th Series				
^{212}Pb	0.02770	0.01796	0.01917	
Total	**0.60400**	**0.51678**	**0.54373**	**0.604**
^{40}K	0.0417	0.03780	0.03995	0.0417

3.7 Calculation of absorbed dose rate in air

The radiation effects in the air can be expressed in terms of the exposure rate or the absorbed dose rate in air at 1 m height. In this study the absorbed dose rate D (nGy/h) in air at a height of 1 m above ground surface was calculated from the measured activity concentrations of ^{238}U, ^{232}Th and ^{40}K using different dose-rate conversion factors as shown in table (3.7) (Kohshi et .al, 2001).

D (nGy/h) = concentrations (Bq/kg) x conversion factor (nGyh^{-1}/ Bqkg^{-1}) 3.2

3.8 Annual effective dose

Total radiation risk to an individual organism is measured by annual effective dose (H), thus the estimated absorbed dose rates in air at 1 m height were converted into annual effective dose using the following formula:

H (µSv/y) = D (nGy/ h) x 24 h x 365.25 d x 0.2 x 0.7 Sv/Gy x 10^{-3} …….. (3.3)

0.7 Sv/Gy 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).

The absorbed gamma dose rate(nGy/h) 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) SATIO, MCNP, GAINT and UNSCEAR and annual effective dose(μSv/y) see tables (4.7 to 4.12), and figures (4.7 to 4.12)

3.9 X-Ray fluorescence (XRF)

A typical (XRF) arrangement consists of a primary irradiation source and a detection system for monitoring the secondary irradiation emitted by the sample. The (XRF) unit includes: The radio isotopic sources: ^{109} Cd ($T_{1/2}$=1.3y), emitting Ag, K (22.2 kev X-ray).

Si (Li) detector: The most widely used method for detection of X-rays is a Si (Li) semiconductor detector. Ionizing radiation falling on a semi-conductor crystal such as Si (Li) produces ion-pairs which were collected by the electric field applied externally. The detector gives an electrical pulse which is proportional to the energy of incident ionizing radiation. Semi-conductor detector has many advantages. They are compact and convenient, with fast rise-time of output pulses, linear responses over a wide energy range and excellent energy resolution. The Si (Li) detector has proved to be a useful and appropriate tool for energy dispersive (XRF) system. It has an adequate energy resolution to resolve most of (K_α) lines from adjacent elements. It is optimum over an energy range from (1 to 100) KeV. Si (Li) detector energy dispersive (XRF) systems are suitable for analyzing the elements from Al to uranium (Gricken and Markowicy,2012).

Si (Li) detector (Canberra, model SL80175), 5 mm thick, with an active area of 80 mm^2 and a resolution of 171 eV (for the 5.9 KeV X-ray of ^{55}Fe). The detector

is cooled by liquid nitrogen and is equipped with a Be-window, a preamplifier, amplifier and high voltage supply.

Preamplifier: A charge (Q) released in the detector flows into an input circuit of total capacitance (C) produces a voltage signal (Q/c). So the first element in the signal processing chain is the preamplifier, which is provided as an interface between the detector and the pulse processing electronics that follow. The preamplifier is usually located as close as possible to the detector. Amplifier: The primary function of the amplifier is to amplifier the single received from the detector-preamplifier combination to a level at which the latter circuit can perform accurate amplitude analysis. But an equally important function is to apply filters, which suppress the extremely low and extremely high frequencies, where the signal noise ratio is poorest. In order to obtain an improved energy resolution, the voltage amplitude of the pulse at the amplifier output should be proportional to the detected x-ray photon energy.

The amplifier is also equipped with a pile-up rejection circuit, which is important in (XRF) work with its high count rates

Laboratory Equipment for sample`s preparation such as: (Hydraulic Press capacity 30 tons, pressing pellet die, 32 mm diameter).

Multichannel analyzer (MCA) is used to measure the height of each amplifier output and t represents this amplitude by a digital number. This is Analogue to digital conversion (ADC) process. This digital information determines the memory address to which count must beaded. The input gate on the (ADC) prevents signal entering the system while an earlier one is being processed. Finally the spectrum of the analyzed sample is obtained see Fig (3.6).

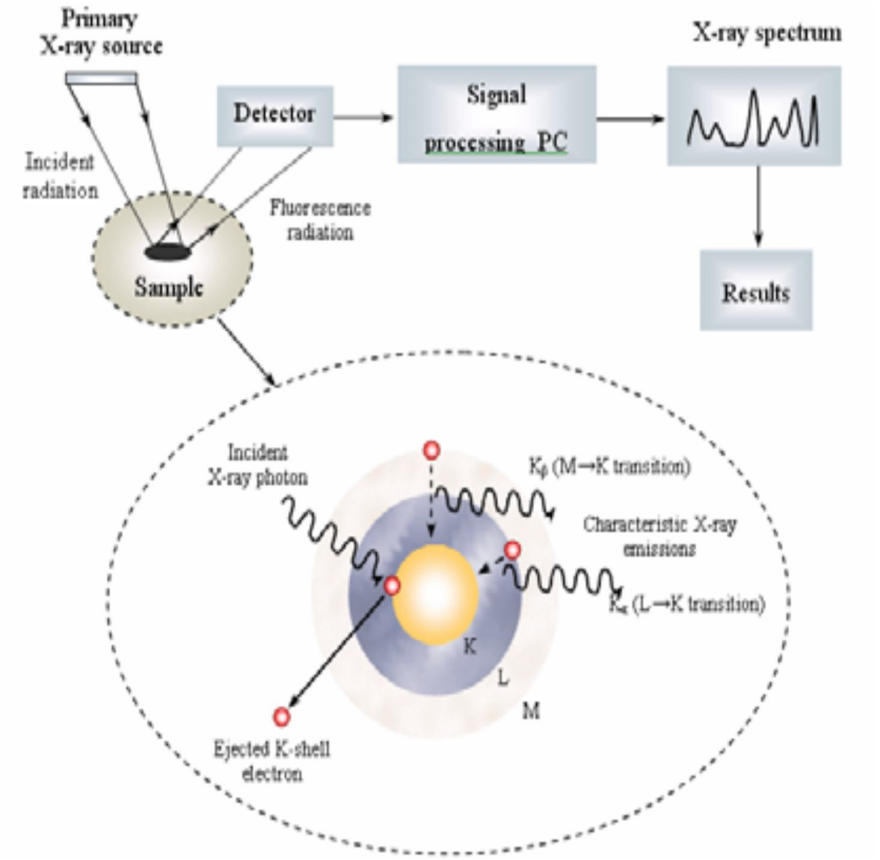

Fig. (3.6): A schematic view of the (XRF) principle and measuring setup.

Fig (3.7): A general view of the (XRF) measuring arrangement

3.9.1 Standard material of XRF

Standards (such as certified reference materials) are required for quantitative analysis. Standard concentrations should be known to a better degree of precision and accuracy than is required for the analysis. Standards should be of the same matrix as samples to be analyzed, standards should vary independently in concentration when empirical absorption corrections are used.

The details concerning the criteria for qualification as a recommended value can be found in the report (IAEA, RL, 112) “report on the inter comparison run IAEA-Soil-7(1): trace elements in soil” and trace elements in Hay (powder) - IAEA-V 10.

This sample is intended to be used as a reference material for the measurement of trace elements in soil samples. It can also be used as a quality control material for the assessment of a laboratory’s analytical work, for the validation of analytical methods and for quality assurance within a laboratory.

3.9.2 System calibration of XRF

Calibration is one of the important steps for quantitative analysis. In order to calculate the concentration of the different elements in a sample, energy calibration of the (ED-XRF) system was carried out using thick standard. The system calibration was usually done by using pure metal foils to calculate the sensitivity of the spectrometer system.

In this work a soil, rock and plant samples (South Kordofan State) were used to incubate for (1000 sec) at the same geometry of the samples and the same time. Calibrate the system energy by the two elements iron, zinc, and the energy orbit K- alpha and K- beta as shown in spectrum Fig (3.8) and table (3.8).

The instrumental constants were measured by using quantitative analysis by fundamental parameters software for K-line and L- line elements. The energy calibration for the system was carried out regularly before each measurement

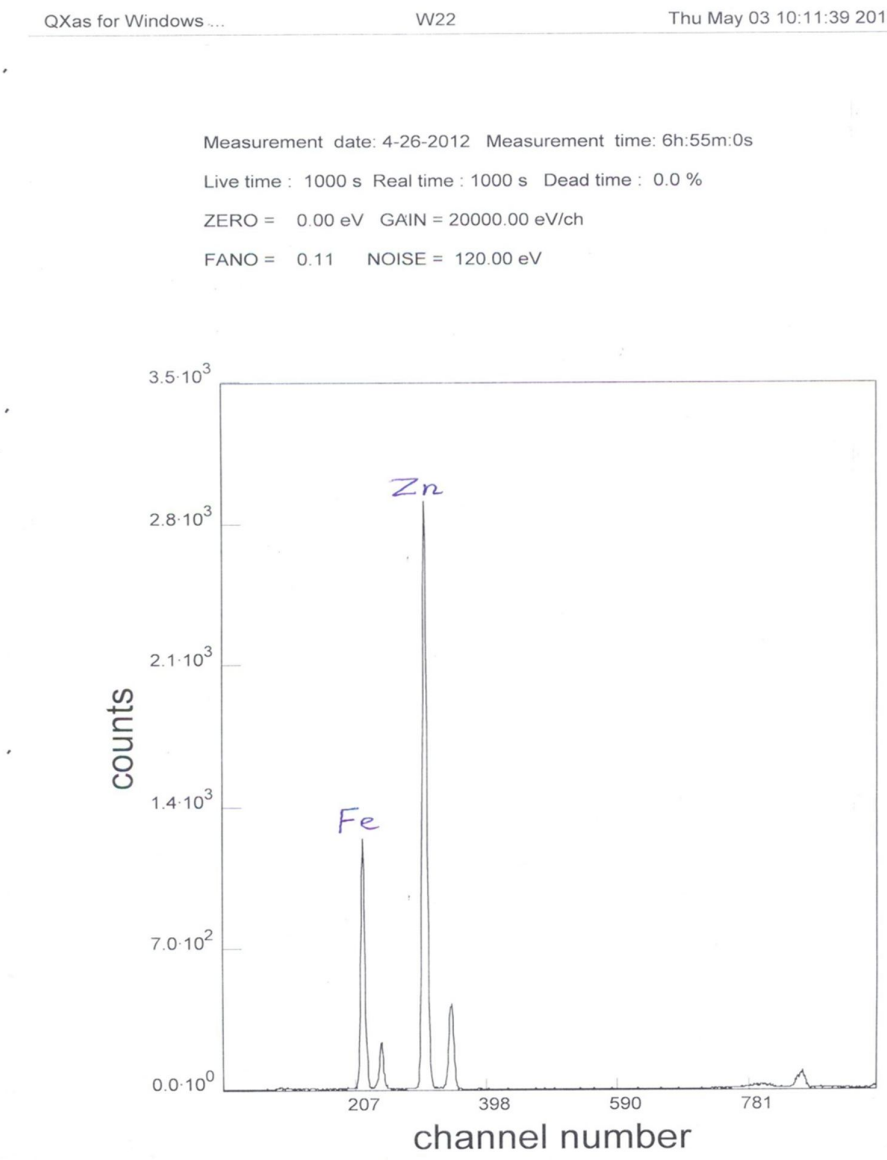

Fig. (3.8): Plot of energy calibration of the system illustrating peak of the Fe and Zn.

Table (3.8): Energy calibration (KeV) of the system illustrating K-line of Fe and Zn.

Elements	K- alpha energy	K- beta energy
Fe	6.398	7.057
Zn	8.630	9.570

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 The results of gamma spectroscopy measurements

Activity concentration of gamma-emitting radionuclides in soil, rock and plant samples from different locations in South Kordofan State were calculated tables(4.1,4.3 and 4.5) for ^{238}U, ^{232}Th and^{40} K based on secular equilibrium assumption, for ^{238}U, ^{232}Th series and ^{40}K concentrations were estimated tables (4.2, 4.4 and 4.6) and figures (4.1 to 4.6).

Table (4.1): Activity concentrations (Bq/kg) of gamma emitter's from^{238}U, ^{232}Th and ^{40}Kin soil samples

Sample code	Location	^{238}U	^{232}Th	^{40}K
S1	Katla	190.47	387.87	2100.52
S2	Katla	170.31	329.79	2130.74
S3	Katla	117.57	217.36	1775.62
S4	Walaey	205.37	303.18	1684.95
S5	Walaey	112.42	189.63	1632.06
S6	Walaey	203.34	406.61	2168.52
S7	Kogoriea	166.35	248.46	1601.84
S8	Kogoriea	163.47	291.93	1707.62
S9	Kogoriea	118.31	224.85	989.81
S10	El karko	131.26	251.84	1775.62
S11	El karko	134.55	267.20	1692.51
S12	El karko	112.83	195.62	1677.39
S13	El funda	49.61	71.95	1647.17
S14	El funda	48.37	69.33	1677.39
S15	El funda	66.51	106.81	1669.84
S16	El netil	53.49	76.82	1609.39

S17	El netil	42.01	61.83	1579.17
S18	El netil	52.91	79.82	1367.61
S19	Sallara	66.52	109.43	1503.61
S20	Sallara	82.78	118.79	1367.61
S21	Sallara	74.82	142.41	1548.95
S22	Hajer el sultan	62.34	95.94	1276.94
S23	Hajer el sultan	65.77	83.19	732.92
S24	Hajer el sultan	61.79	82.82	649.80
S25	El fous	67.64	99.69	1246.71
S26	El fous	70.16	77.19	1412.94
S27	El fous	58.12	85.44	1526.28
S28	Kakara	70.19	137.91	1526.28
S29	Kakara	73.29	132.66	1533.83
S30	Kakara	66.84	93.31	1624.50
S31	Kelara	55.65	79.82	1632.06
S32	Kelara	45.57	63.71	1843.62
S33	Kelara	59.59	84.69	1654.73
S34	Tondiya	91.10	106.06	1329.83
S35	Tondiya	51.35	68.58	1586.72
S36	Tondiya	47.77	61.01	1594.28
S37	Gelogical camp	34.06	28.86	604.47
S38	Uro east	245.75	44.22	831.14
S39	Uro west	868.24	306.18	ND
S40	Uro market	241.99	34.85	680.02
S41	Uro middle	93.73	22.11	400.46
S42	Dar el salam school	111.21	28.48	445.79
S43	Um takatik	69.08	26.61	415.57
S44	Um takatik	42.68	35.23	332.46

S45	Um takatik	21.89	7.12	226.67
S46	Um takatik(Termites)	49.50	31.10	347.57
S47	Kurun	164.45	53.59	ND
S48	Kurun hill	65.99	32.98	423.13
S49	Kurun	204.04	32.98	423.13
S50	Kurun	31.46	23.61	430.68
S51	Abu galaha	31.09	20.99	468.46
S52	Tumluk hill	86.59	27.73	785.81
S53	Tumluk hill	87.73	32.98	763.14
S54	Tumluk	79.00	25.48	672.47
S55	Aryab camp	35.62	23.23	506.24
S56	Aryab (trench)	18.37	14.62	808.47
S57	Aryab	57.97	19.86	710.25
S58	Uro hill height	211.99	41.59	1201.38
S59	Near Uro Village	204.86	33.35	1065.37
S60	Near Uro hill	164.64	28.86	536.46
S61	Uro Village	217.73	49.09	ND
S62	Uro Village	19.95	37.85	ND
S63	Tirmi stream	89.67	28.11	491.13
S64	Stream between Trimi and Uro	80.59	22.11	1088.04
S65	Western north of Uro	118.83	31.10	483.57
S66	El layoon farm	256.02	37.85	800.92
S67	El layoon village	16.63	22.11	559.13
S68	El layoon	15.44	16.49	498.68
S69	El layoon	161.02	38.97	ND
Mean		**108.82**	**98.03**	**1059.13**
SD		**112.35**	**97.39**	**610.11**
Min		**15.44**	**7.12**	**226.67**
Max		**868.24**	**406.61**	**2168.52**

Table (4.2): Activity concentrations (Bq/kg) of gamma emitters from ^{238}U, ^{232}Th series and ^{40}K in soil samples

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K
S1	Katla	387.87	161.65	219.29	2100.52
S2	Katla	329.79	145.76	194.85	2130.74
S3	Katla	217.35	101.37	133.76	1775.62
S4	Walaey	303.18	201.10	209.64	1684.95
S5	Walaey	189.63	101.37	123.47	1632.01
S6	Walaey	406.61	172.61	234.08	2168.52
S7	Kogoriea	248.46	161.65	171.06	1601.84
S8	Kogoriea	291.93	143.02	183.92	1707.62
S9	Kogoriea	224.85	100.28	136.33	989.81
S10	El karko	251.84	113.98	148.55	1775.62
S11	El karko	267.20	120.55	148.55	1692.51
S12	El karko	195.62	104.11	121.54	1677.39
S13	El funda	71.95	47.12	52.09	1647.17
S14	El funda	69.33	46.58	50.16	1677.39
S15	El funda	106.81	63.56	69.45	1669.84
S16	El netil	76.82	54.29	52.73	1609.39
S17	El netil	61.83	38.36	45.66	1579.17
S18	El netil	79.82	49.86	55.95	1367.61
S19	Sallara	109.43	59.73	73.31	1503.61
S20	Sallara	118.79	76.17	89.39	1367.61
S21	Sallara	142.41	64.11	85.53	1548.95
S22	Hajer el sultan	95.94	59.73	64.95	1276.94
S23	Hajer el sultan	83.19	64.66	66.88	732.92
S24	Hajer el sultan	82.82	58.63	64.95	649.80

S25	El fous	99.69	69.04	66.24	1246.71
S26	El fous	77.19	69.59	70.74	1412.94
S27	El fous	85.44	56.44	59.81	1526.28
S28	Kakara	137.91	58.08	82.31	1526.28
S29	Kakara	132.66	66.85	79.74	1533.83
S30	Kakara	93.31	59.73	73.95	1624.50
S31	Kelara	79.82	55.34	55.95	1632.06
S32	Kelara	63.71	45.48	45.66	1843.62
S33	Kelara	84.69	54.25	64.95	1654.73
S34	Tondiya	106.06	87.67	94.53	1329.83
S35	Tondiya	68.58	49.32	53.38	1586.72
S36	Tondiya	61.01	46.03	49.52	1594.28
S37	Gelogical camp	28.86	37.26	30.87	604.47
S38	Uro east	44.22	276.72	214.79	831.14
S39	Uro west	306.18	684.40	1052.08	ND
S40	Uro market	34.85	260.83	223.15	680.02
S41	Uro middle	22.11	101.92	85.53	400.46
S42	Dar el salam school	28.48	122.74	99.68	445.79
S43	Um takatik	26.61	78.36	59.81	415.57
S44	Um takatik	35.23	45.48	39.87	332.47
S45	Um takatik	7.12	21.92	21.86	226.67
S46	Um takatik(Termites)	31.12	52.06	46.94	347.57
S47	Kurun	53.59	168.77	160.13	ND
S48	Kurun hill	32.98	65.76	66.24	423.13
S49	Kurun	32.98	216.44	191.64	423.13
S50	Kurun	23.62	33.97	28.94	430.68
S51	Abu galaha	20.99	34.52	27.65	468.46
S52	Tumluk hill	27.73	91.51	81.67	785.81

S53	Tumluk hill	32.98	93.15	82.31	763.14
S54	Tumluk	25.48	78.91	79.09	672.47
S55	Aryab camp	23.23	37.81	33.44	506.24
S56	Aryab (trench)	14.62	18.08	18.65	808.47
S57	Aryab	19.86	61.92	54.02	710.25
S58	Uro hill height	41.59	228.49	195.49	1201.38
S59	Near Uro Village	33.35	218.09	191.64	1065.37
S60	Near Uro hill	28.86	181.37	147.91	536.46
S61	Uro Village	49.09	232.88	202.57	ND
S62	Uro Village	37.85	10.96	28.94	ND
S63	Tirmi stream	28.11	89.32	90.03	491.13
S64	Stream betweenTirmi and Uro	22.11	82.74	78.46	1088.09
S65	Western north of Uro	31.10	123.84	113.83	483.57
S66	El layoon farm	37.85	254.80	257.23	800.92
S67	El layoon village	22.11	15.89	17.36	559.13
S68	El layoon	16.49	14.79	16.01	498.68
S69	El layoon	38.97	178.64	143.41	ND
Mean		**98.03**	**104.96**	**112.67**	**1059.13**
SD		**97.39**	**96.58**	**130.83**	**610.11**
Min		**7.12**	**10.96**	**16.08**	**226.67**
Max		**406.61**	**684.4**	**1052.08**	**2168.52**

Table (4.3): Activity concentrations (Bq/kg) of gamma emitters from ^{238}U, ^{232}Thand ^{40}K in rock samples

Sample code	Location	^{238}U	^{232}Th	^{40}K
R70	Katla	38.75	37.101	ND
R71	Walaey	250.09	102.68	1360.05
R72	Kogoriea	18.64	19.11	90.67
R73	El karko	55.63	152.53	ND
R74	EL funda	117.43	134.16	1722.73
R75	El netil	77.59	92.19	1700.06
R76	Sallara	102.23	120.29	1866.29
R77	Hajer el sultan	91.08	99.69	1624.50
R78	El fous	110.51	111.30	1601.84
R79	Kakara	223.81	228.60	1586.72
R80	Kelara	79.29	101.56	1828.51
R81	Tondiya	99.01	163.02	1881.40
R82	Um takatik hill	685.45	246.96	1412.94
R83	Kurun hill	312.25	172.01	ND
R84	Kurun hill	653.08	218.86	ND
R85	Beside kurun hill	913.09	326.79	1866.29
R86	Beside kurun hill	792.05	258.96	1609.39
R87	Tumluk	119.14	29.23	ND
R88	Aryab	51.371	38.60	438.24
R89	Uro hill	551.85	198.62	1095.59
R90	Tirmi hill	93.18	10.87	521.35
R91	Uro market hill	785.18	278.44	1586.74
Mean		**282.76**	**142.79**	**1081.50**
SD		**294.96**	**90.28**	**766.05**
Min		**18.64**	**10.87**	**90.67**
Max		**913.09**	**326.79**	**1881.40**

Table (4.4): Activity concentrations (Bq/kg) of gamma emitters from ^{238}U, ^{232}Th series and ^{40}K in rock samples

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K
R70	Katla	37.10	38.91	38.58	ND
R71	Walaey	102.68	271.24	228.94	1360.05
R72	Kogoriea	19.11	18.63	18.65	90.67
R73	El karko	152.53	14.27	111.25	ND
R74	EL funda	134.16	117.81	117.04	1722.73
R75	El netil	92.19	76.71	78.46	1700.06
R76	Sallara	120.29	100.28	104.18	1866.29
R77	Hajer el sultan	99.69	95.35	86.82	1624.50
R78	El fous	111.30	112.33	108.68	1601.84
R79	Kakara	228.60	225.76	221.86	1586.72
R80	Kelara	101.56	71.78	86.82	1828.51
R81	Tondiya	163.02	85.48	112.54	1881.40
R82	Um takatik hill	246.96	704.68	666.23	1412.94
R83	Kurun hill	172.01	251.51	372.99	ND
R84	Kurun hill	218.86	684.95	621.22	ND
R85	Beside kurun hill	326.79	941.94	884.24	1866.29
R86	Beside kurun hill	258.96	817.56	766.55	1609.39
R87	Tumluk	29.23	127.67	110.61	ND
R88	Aryab	38.59	56.44	46.30	438.24
R89	Uro hill	198.62	573.17	530.54	1095.59
R90	Tirmi hill	10.87	100.82	85.53	521.35
R91	Uro market hill	278.44	826.32	744.05	1586.72
Mean		**142.79**	**286.98**	**279.19**	**1254.27**
SD		**90.28**	**308.94**	**281.7**	**613.45**
Min		**10.87**	**14.25**	**18.65**	**90.67**
Max		**326.79**	**941.94**	**884.24**	**1881.40**

Table (4.5): Activity concentrations (Bq/kg) of gamma emitters from ^{238}U, ^{232}Th ^{137}Cs and ^{40}K in crops samples

Sample code	Location	Type	^{238}U	^{232}Th	^{137}Cs	^{40}K
C 92	Katla	Sorghum	5.56	11.87	ND	340.01
C 94	Walaey	Mango	10.17	12.74	ND	453.35
C 95	Walaey	Tomato	20.19	20.61	ND	1397.83
C 97	Kogoriea	Sorghum	8.85	11.24	1.91	302.23
C 99	El karko	Sorghum	5.88	11.71	ND	354.18
C 103	Hajer el sultan	Sorghum	4.36	0.47	ND	226.67
C 105	El layoon	Chili	29.78	18.74	19.10	1284.49
C 109	Kabous	Dry Tomato	4.24	9.84	0.96	1142.82
C 110	El abbasiya	Tomato	34.42	41.22	ND	1662.28
C 111	El biteira	Okra	3.29	7.50	ND	684.47
C 113	El biteira	Tomato	12.95	14.05	ND	1681.17
Mean			**12.70**	**14.54**	**7.32**	**866.32**
SD			**10.81**	**10.32**	**10.21**	**574.60**
Min			**3.29**	**0.47**	**0.96**	**226.67**
Max			**34.42**	**41.22**	**19.10**	**1681.17**

Table (4.6): Activity concentrations (Bq/kg) of gamma emitters from ^{238}U, ^{232}Th series, ^{137}Cs and ^{40}K in crops samples

Sample code	Location	Type	^{212}Pb	^{214}Pb	^{214}Bi	^{137}Cs	^{40}K
C 92	Katla	Sorghum	11.87	10.05	1.07	ND	340.01
C 94	Walaey	Mango	12.74	8.77	11.58	ND	453.35
C 95	Walaey	Tomato	20.61	8.22	32.15	ND	1397.83
C 97	Kogoriea	Sorghum	11.24	9.13	8.57	1.91	302.23
C 99	El karko	Sorghum	11.71	1.71	10.05	ND	354.18
C 103	Hajer el sultan	Sorghum	0.47	0.68	8.04	ND	226.67
C 105	El layoon	Chili	18.74	27.40	32.15	19.10	1284.49
C 109	Kabous	Dry Tomato	9.84	2.05	6.43	0.96	1142.82
C 110	El abbasiya	Tomato	41.22	10.96	57.88	ND	1662.28
C 111	El biteira	Okra	7.50	1.29	5.30	ND	684.47
C 113	El biteira	Tomato	14.05	8.22	17.68	ND	1681.17
Mean			**14.54**	**8.04**	**17.36**	**7.32**	**866.32**
SD			**10.32**	**7.51**	**16.91**	**10.21**	**574.60**
Min			**0.47**	**0.68**	**1.07**	**0.96**	**226.67**
Max			**41.22**	**27.40**	**57.88**	**19.10**	**1681.17**

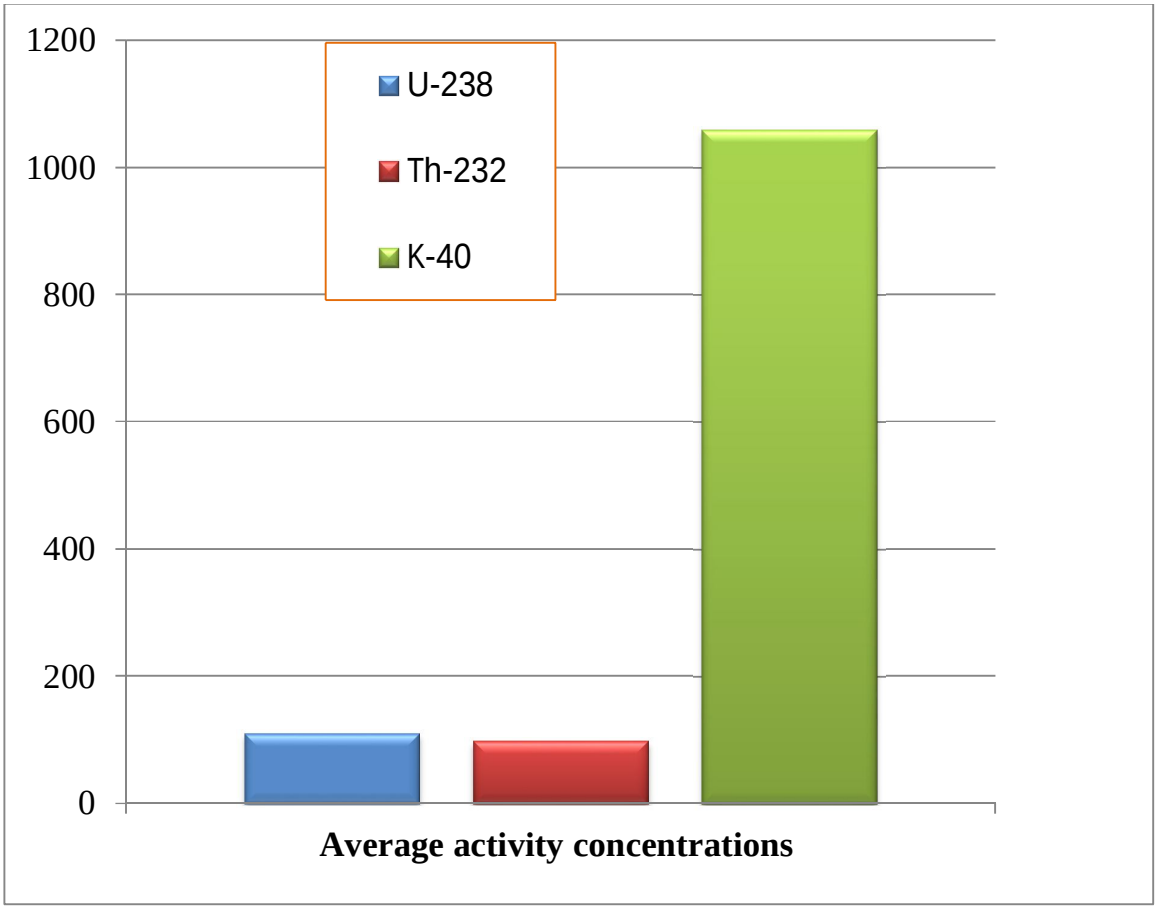

Fig. (4.1): Average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples from South Kordofan State

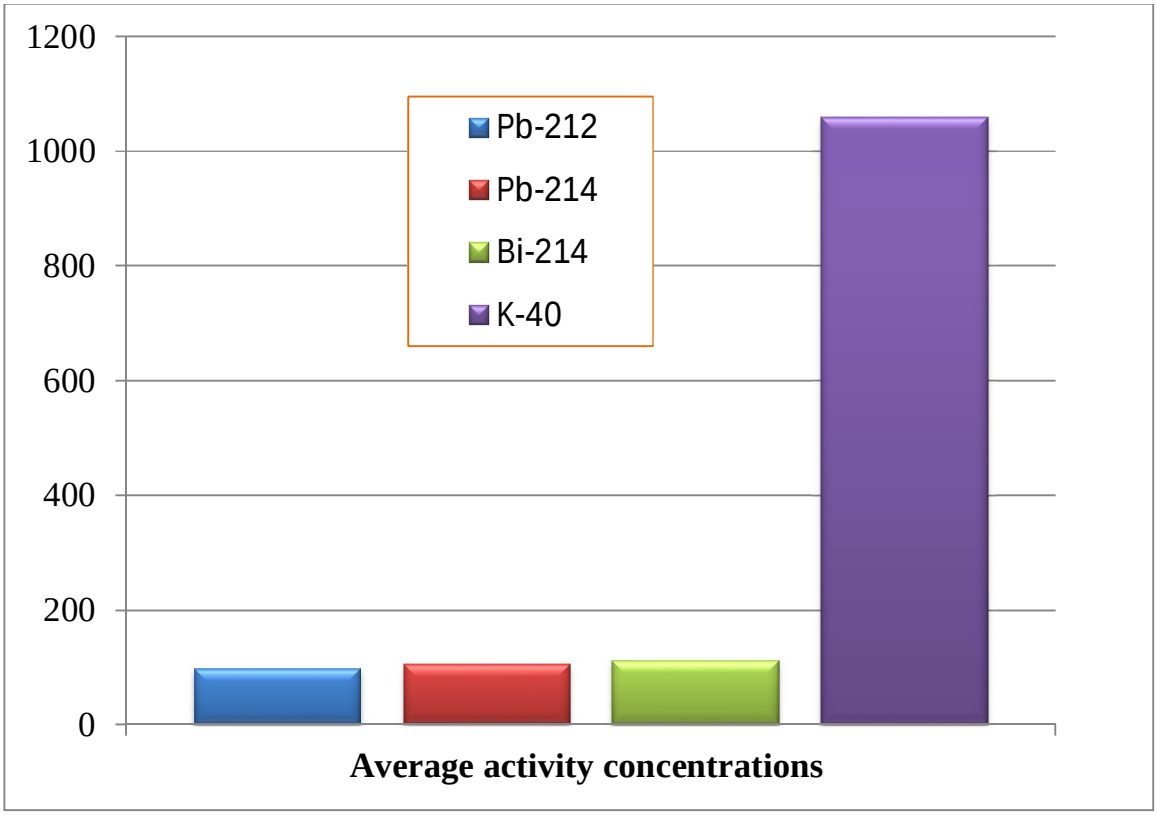

Fig. (4.2): Average activity concentrations of ^{238}U, ^{232}Th series and ^{40}K in soil samples from South Kordofan State

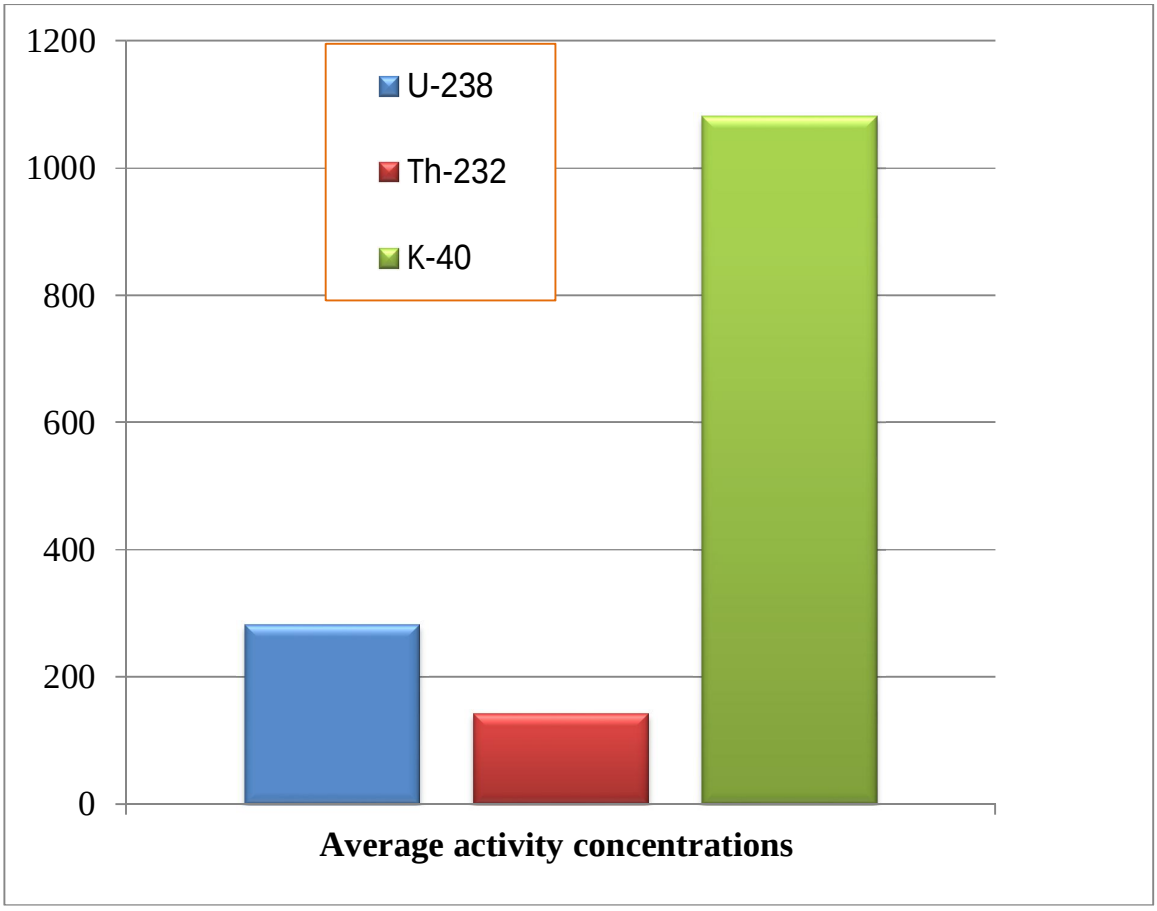

Fig. (4.3): Average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in rock samples from South Kordofan State

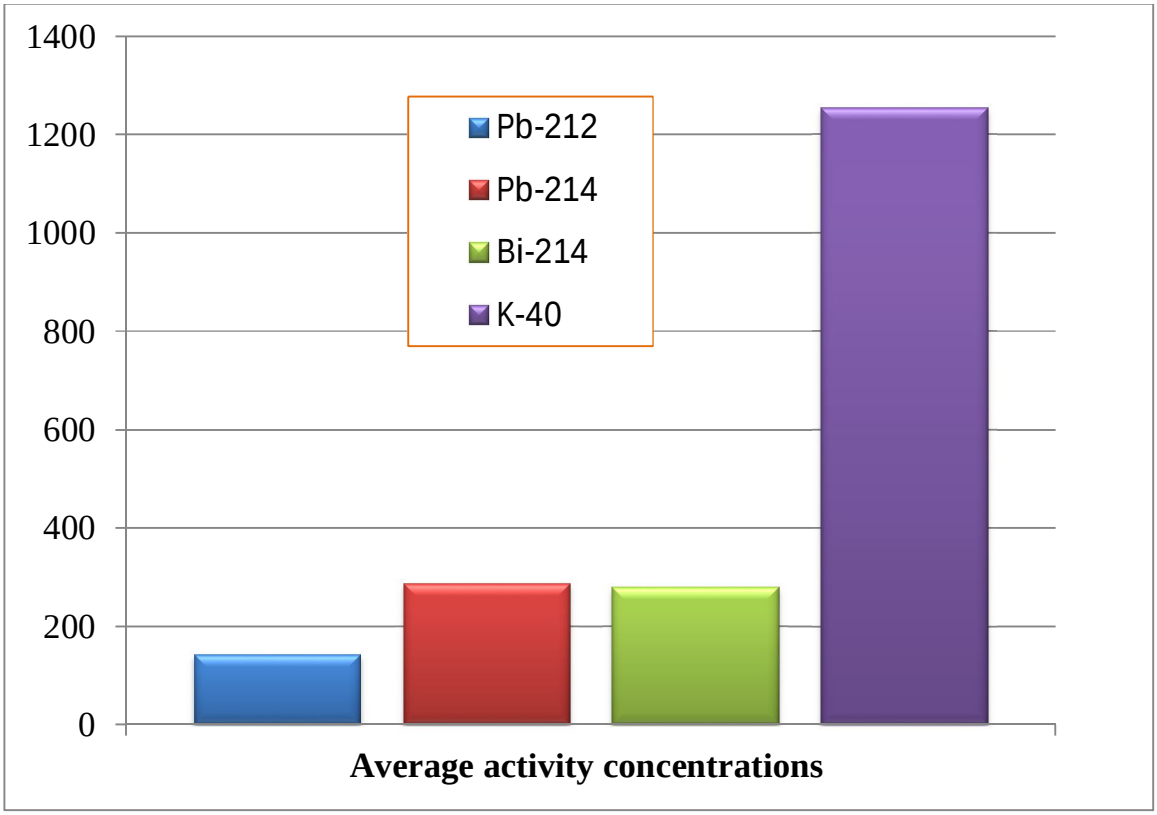

Fig. (4.4): Average activity concentrations of ^{238}U, ^{232}Th series and ^{40}K in rock samples from South Kordofan State

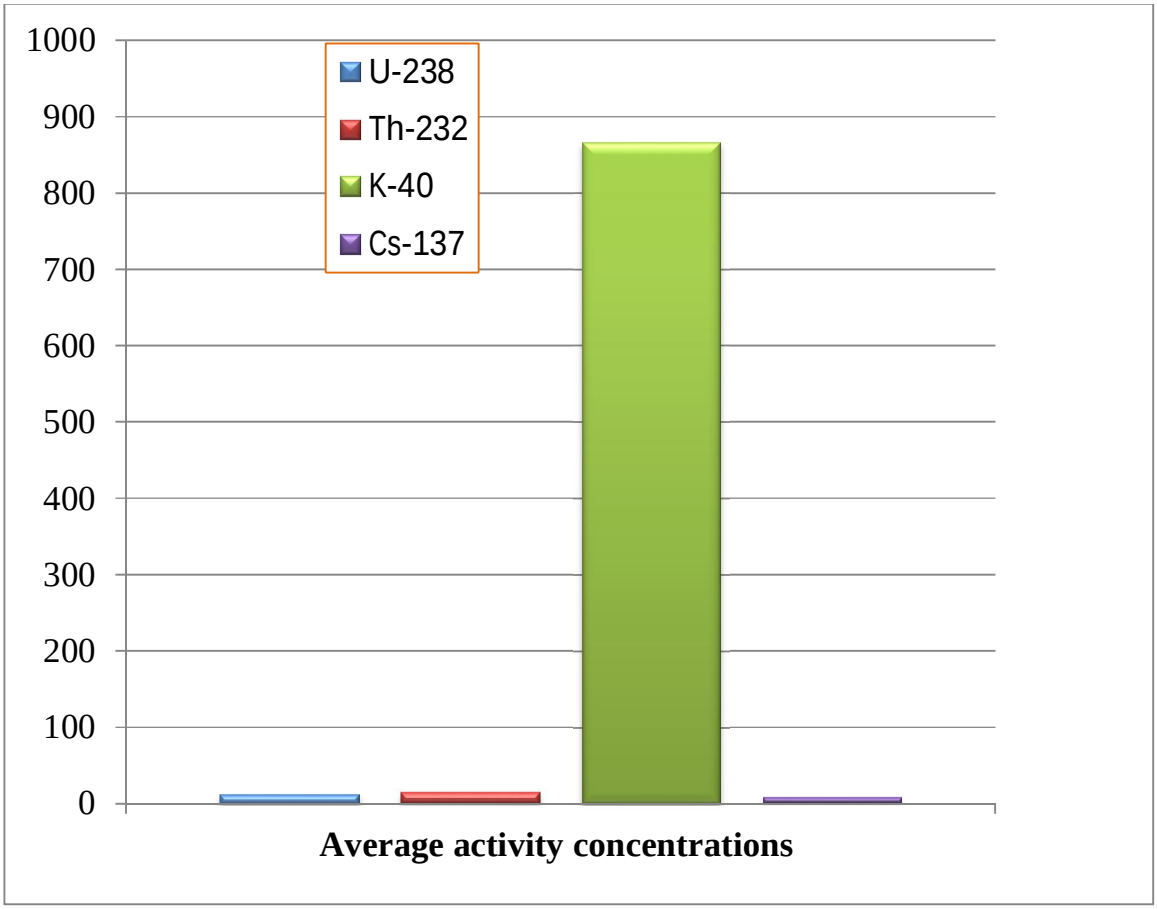

Fig. (4.5): Average activity concentrations of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in crops samples from South Kordofan State

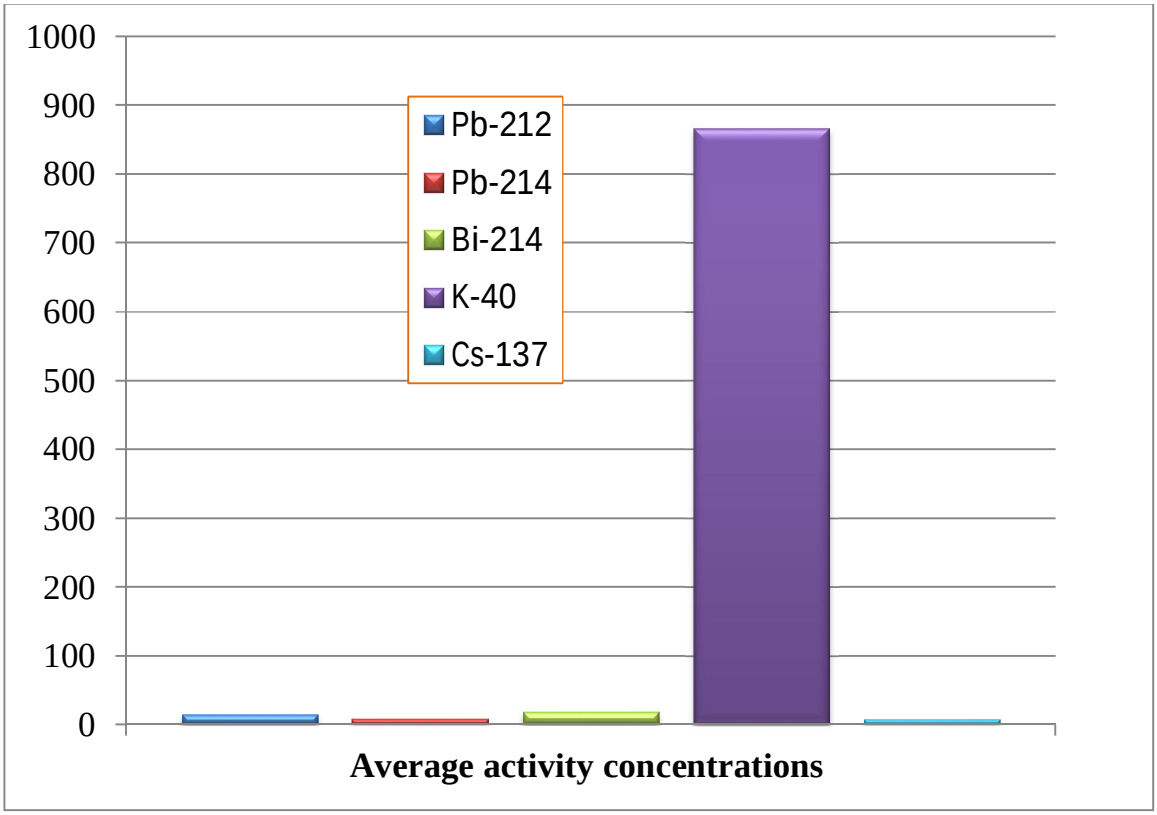

Fig. (4.6): Average activity concentrations of ^{238}U, ^{232}Th series, ^{137}Cs and ^{40}K in crops samples from South Kordofan State

4.2Annual effective dose results

The absorbed gamma dose rate(nGy/h) 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) SATIO, MCNP, GAINT and UNSCEAR and annual effective dose(μSv/y) see tables (4.7 to 4.12), and figures (4.7 to 4.12)

Table (4.7): 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 South Kordofan State using different DRCFs in soil samples

DRCFs	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
SAITO					
Mean ±SD	50.38 ±52.02	59.21 ±58.83	44.17 ±25.44	153.76 ±104.28	188.70±127.97
Range	7.15 – 402.00	4.30 - 245.59	9.45- 90.43	23.89 - 586.93	29.32 - 720.30
Contribution %	32.77	38.51	28.73		
MCNP					
Mean ±SD	41.45 ± 42.80	50.66 ± 50.33	40.04 ± 23.06	132.14 ± 88.72	162.17 ±108.88
Range	5.88-330.73	3.68-210.13	8.57-81.97	20.59 - 488.96	25.27 - 600.07
Contribution %	31.37	38.34	30.30		
GEANT					
Mean ±SD	43.52 ±44.94	53.30 ±52.96	42.31 ±24.37	139.14 ±93.34	170.75 ±114.55
Range	6.17 - 347.26	3.87 - 221.09	9.06- 86.63	21.68 - 513.74	26.61 - 630.48
Contribution %	31.28	38.31	30.41		
UNSCEAR					
Mean ±SD	50.27 ± 51.91	59.21 ± 58.83	44.17 ± 25.44	153.65 ±104.20	188.56 ±127.87
Range	7.13 - 401.13	4.30 - 245.59	9.45- 90.43	23.87 - 586.06	29.29- 719.23
Contribution %	32.72	38.54	28.75		

Table (4.8): Statistical summary of absorbed dose rate in air at 1 m height(nGy/h) (mean and range) ^{238}U,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual e South Kordofan State using different DRCFs in soil samples

DRCFs	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose R
SAITO					
Mean ±SD	2.72 ± 2.70	5.73± 5.27	45.18 ±52.46	44.17 ±25.44	97.79 ±62.2
Range	0.20 - 11.26	0.60 - 37.37	6.42 - 421.88	9.45- 90.43	13.25 - 467.
Contribution %	2.78	5.86	46.20	45.17	
MCNP					
Mean ±SD	1.76 ± 1.75	4.36 ± 4.01	38.14 ± 44.29	40.04 ± 23.06	84.29 ± 52.
Range	0.13 - 7.30	0.45 - 28.40	5.42 - 356.12	8.57- 81.97	10.93 -390.
Contribution %	2.09	5.17	45.25	47.50	
GEANT					
Mean ±SD	1.88 ± 1.87	4.56 ± 4.19	40.06 ± 46.52	42.31 ± 24.37	88.81 ± 55.
Range	0.14 - 7.79	0.48 - 29.72	5.69 - 374.06	9.06- 86.63	11.49 - 409.
Contribution %	2.12	5.13	45.11	47.64	
UNSCEAR					
Mean ±SD	59.21 ± 58.83	48.49 ± 44.61	52.05 ± 60.45	44.17 ± 25.44	203.92±145
Range	4.30 - 245.59	5.06 - 316.19	7.40 - 486.06	9.45- 90.43	33.98 - 987.
Contribution %	29.04	23.78	25.52	21.66	

Table (4.9): Statistical summary of absorbed dose rate in air at 1 m height(nGy/h) (mean and range) ^{238}U,^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effectiv Kordofan State using different DRCFs in rock samples

DRCFs	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	A
SAITO					
Mean ±SD	130.92 ±136.57	86.25 ± 54.53	45.10± 31.94	262.27± 197.13	32
Range	8.63 - 422.76	6.56 - 197.38	3.78 - 78.45	23.96 - 697.96	2
Contribution %	49.92	32.89	17.20		
MCNP					
Mean ±SD	107.71 ±112.36	73.80 ± 46.65	40.88 ± 28.96	222.39 ±165.04	27
Range	7.10 - 347.81	5.62- 168.88	3.43 - 71.12	20.40 - 587.24	2
Contribution %	48.43	33.18	18.38		
GEANT					
Mean ±SD	113.09 ±117.97	77.64± 49.09	43.21 ± 30.60	233.94± 173.47	28
Range	7.46 -365.20	5.91 -177.68	3.62- 75.16	21.47 - 617.44	2
Contribution %	48.34	33.19	18.47		
UNSCEAR					
Mean ±SD	130.63±136.27	86.25 ± 54.53	45.10 ± 31.94	261.98± 196.85	32
Range	8.61- 421.85	6.56 - 197.38	3.78- 78.45	23.94 - 697.05	2
Contribution %	49.86	32.92	17.22		

Table (4.10): Statistical summary of absorbed dose rate in air at 1 m height(nGy/h) (mean and range) ^{238}U, ^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual e South Kordofan State using different DRCFs in rock samples

DRCFs	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs .Dose R
SAITO					
Mean ±SD	3.96 ± 2.50	15.67 ± 16.87	111.95±112.96	45.10 ± 31.94	176.68±141
Range	0.30 - 9.05	0.78 - 51.43	7.48 -354.58	3.78- 78.45	12.81 -492.
Contribution %	2.24	8.87	63.36	25.53	
MCNP					
Mean ±SD	2.56 ± 1.62	11.91 ± 12.82	94.50 ± 95.35	40.88 ± 28.96	149.86±118
Range	0.20 - 5.87	0.59 - 39.09	6.31-299.31	3.43- 71.12	10.86-414.8
Contribution %	1.71	7.95	63.06	27.28	
GEANT					
Mean ±SD	2.74 ±1.73	12.46 ± 13.41	99.26 ±100.16	43.21 ± 30.60	157.67±124
Range	0.21 - 6.26	0.62- 40.90	6.63- 314.38	3.62- 75.16	11.43 - 436.
Contribution %	1.74	7.90	62.95	27.41	
UNSCEAR					
Mean ±SD	86.25 ± 54.53	132.59±142.73	128.98±130.15	45.10 ±31.94	392.92±330
Range	6.57 -197.38	6.59 - 435.18	8.62 - 408.52	3.78- 78.45	32.55 -1118
Contribution %	21.95	33.74	32.83	11.48	

Table (4.11): Statistical summary of absorbed dose rate in air at 1 m height(nGy/h) (mean and range) ^{238}U,^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effectiv Kordofan State using different DRCFs in crops samples

DRCFs	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	A
SAITO					
Mean ±SD	5.88 ± 5.00	8.78 ± 6.23	36.13 ± 23.96	50.79 ± 32.63	6
Range	1.52- 15.94	0.28 - 24.90	9.45 - 70.10	11.75 - 110.15	1
Contribution %	11.58	17.29	71.14		
MCNP					
Mean ±SD	4.84 ± 4.12	7.52 ± 5.33	32.75 ± 21.72	45.10 ± 28.96	5
Range	1.25 - 13.11	0.24 - 21.30	8.57 - 63.55	10.47 - 97.25	1
Contribution %	10.73	16.67	72.62		
GEANT					
Mean ±SD	5.08 ± 4.32	7.91 ± 5.61	34.61 ± 22.96	47.60 ± 30.57	5
Range	1.32 - 13.77	0.26 - 22.41	9.06 - 67.16	11.05 - 102.59	1
Contribution %	10.67	16.62	72.71		
UNSCEAR					
Mean ±SD	5.87 ± 4.99	8.78 ± 6.23	36.13 ± 23.96	50.78 ± 32.62	6
Range	1.52 - 15.90	0.28 - 24.90	9.45 - 70.10	11.75 - 110.12	1
Contribution %	11.56	17.29	71.15		

Table (4.12): Statistical summary of absorbed dose rate in air at 1 m height(nGy/h) (mean and range) ^{238}U,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual e South Kordofan State using different DRCFs in crops samples

DRCFs	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose R
SAITO					
Mean ±SD	0.40 ± 0.29	0.44 ± 0.41	6.96 ± 6.78	36.13 ± 23.96	43.93 ± 29.
Range	0.01 - 1.14	0.04 - 1.50	0.43 - 23.21	9.45 - 70.10	12.73 - 94.
Contribution %	0.91	1.00	15.84	82.24	
MCNP					
Mean ±SD	0.26 ± 0.19	0.33 ± 0.31	5.87 ± 5.73	32.75 ± 21.72	39.22 ± 26.
Range	0.01 - 0.74	0.03 - 1.14	0.36 - 19.59	8.57 - 63.55	11.33 - 83.
Contribution %	0.66	0.84	14.97	83.50	
GEANT					
Mean ±SD	0.28 ± 0.20	0.35 ± 0.33	6.17 ± 6.01	34.61 ± 22.96	41.41 ± 27.
Range	0.01- 0.79	0.03- 1.19	0.38- 20.58	9.06 - 67.16	11.95 - 88.
Contribution %	0.68	0.85	14.90	83.58	
UNSCEAR					
Mean ±SD	8.78 ± 6.23	3.72 ± 3.47	8.02 ± 7.81	36.13 ± 23.96	56.64 ± 36.
Range	0.28 - 24.90	0.31 - 12.66	0.49 - 26.74	9.45 - 70.10	13.76 - 126
Contribution %	15.50	6.57	14.16	63.79	

Table (4.13): Statistical summary of absorbed dose rate in air at 1 m height (nGy/h) (mean and range) ^{238}U, ^{232}Th and ^{40}K with their relative contribution to the total absorbed dose rate and the annual effective Kordofan state using UNSCEAR DRCFs in study sample groups; soil samples, rock samples and crops sa

Sample group	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	A
Soil					
Mean ±SD	50.27 ± 51.91	59.21 ± 58.83	44.17 ± 25.44	153.65 ±104.20	
Range	7.13 - 401.13	4.30 - 245.59	9.45- 90.43	23.87 - 586.06	
Contribution %	32.72	38.54	28.75		
Rock					
Mean ±SD	130.63±136.27	86.25 ± 54.53	45.10 ± 31.94	261.98± 196.85	
Range	8.61- 421.85	6.56 - 197.38	3.78- 78.45	23.94 - 697.05	
Contribution %	49.86	32.92	17.22		
Crops					
Mean ±SD	5.87 ± 4.99	8.78 ± 6.23	36.13 ± 23.96	50.78 ± 32.62	
Range	1.52 - 15.90	0.28 - 24.90	9.45 - 70.10	11.75 - 110.12	
Contribution %	11.56	17.29	71.15		

Table (4.14): Statistical summary of absorbed dose rate in air at 1 m height (nGy/h) (mean and range) ^{238}U,^{232}Th series and ^{40}K with their relative contribution to the total absorbed dose rate and the annual ef South Kordofan state using UNSCEAR DRCFs in study sample groups; soil samples, rock samples and cr

Sample group	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose R
Soil					
Mean ±SD	59.21 ± 58.83	48.49 ± 44.61	52.05 ± 60.45	44.17 ± 25.44	203.92±145
Range	4.30 - 245.59	5.06 - 316.19	7.40 - 486.06	9.45- 90.43	33.98 - 987
Contribution %	29.04	23.78	25.52	21.66	
Rock					
Mean ±SD	86.25 ± 54.53	132.59±142.73	128.98±130.15	45.10 ±31.94	392.92±330
Range	6.57 -197.38	6.59 - 435.18	8.62 - 408.52	3.78- 78.45	32.55 -1118
Contribution %	21.95	33.74	32.83	11.48	
Crops					
Mean ±SD	8.78 ± 6.23	3.72 ± 3.47	8.02 ± 7.81	36.13 ± 23.96	56.64 ± 36.
Range	0.28 - 24.90	0.31 - 12.66	0.49 - 26.74	9.45 - 70.10	13.76 - 126
Contribution %	15.50	6.57	14.16	63.79	

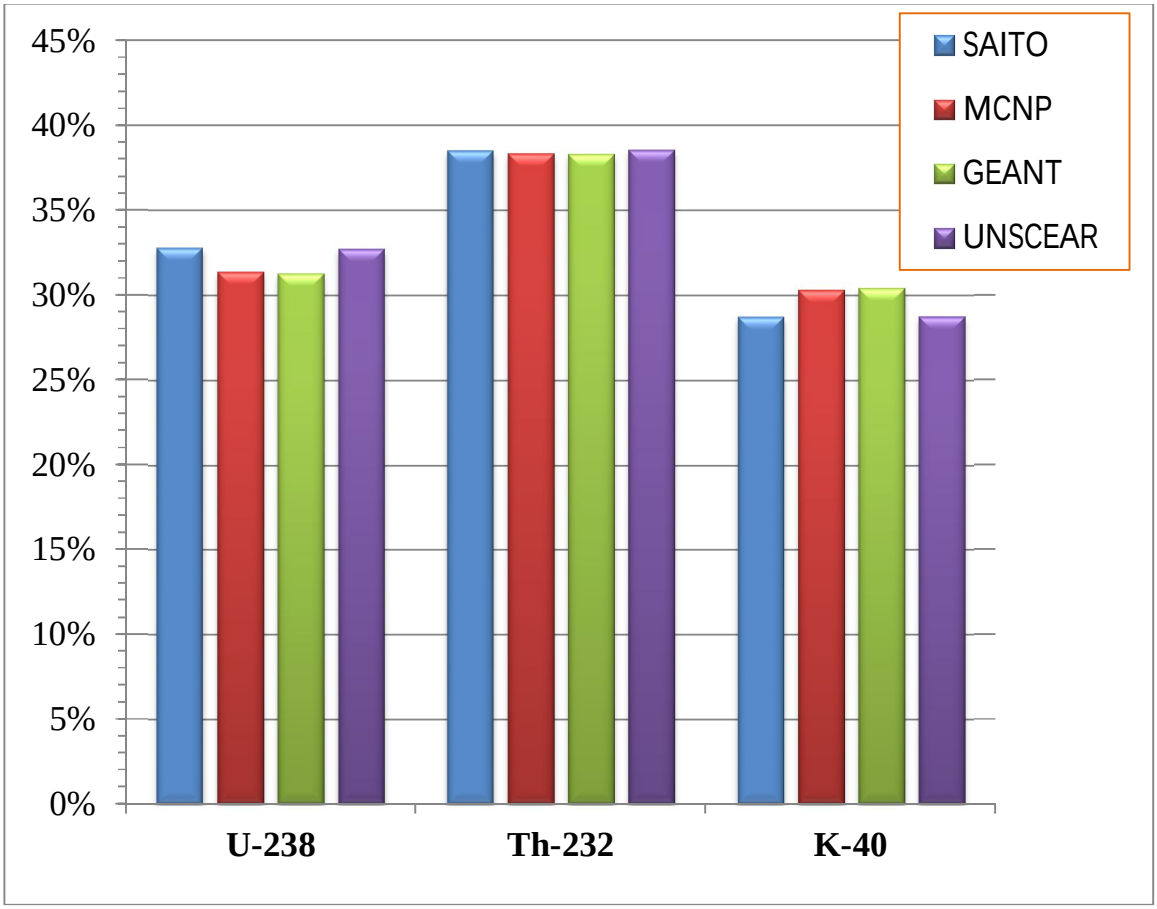

Fig. (4.7): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in soil samples

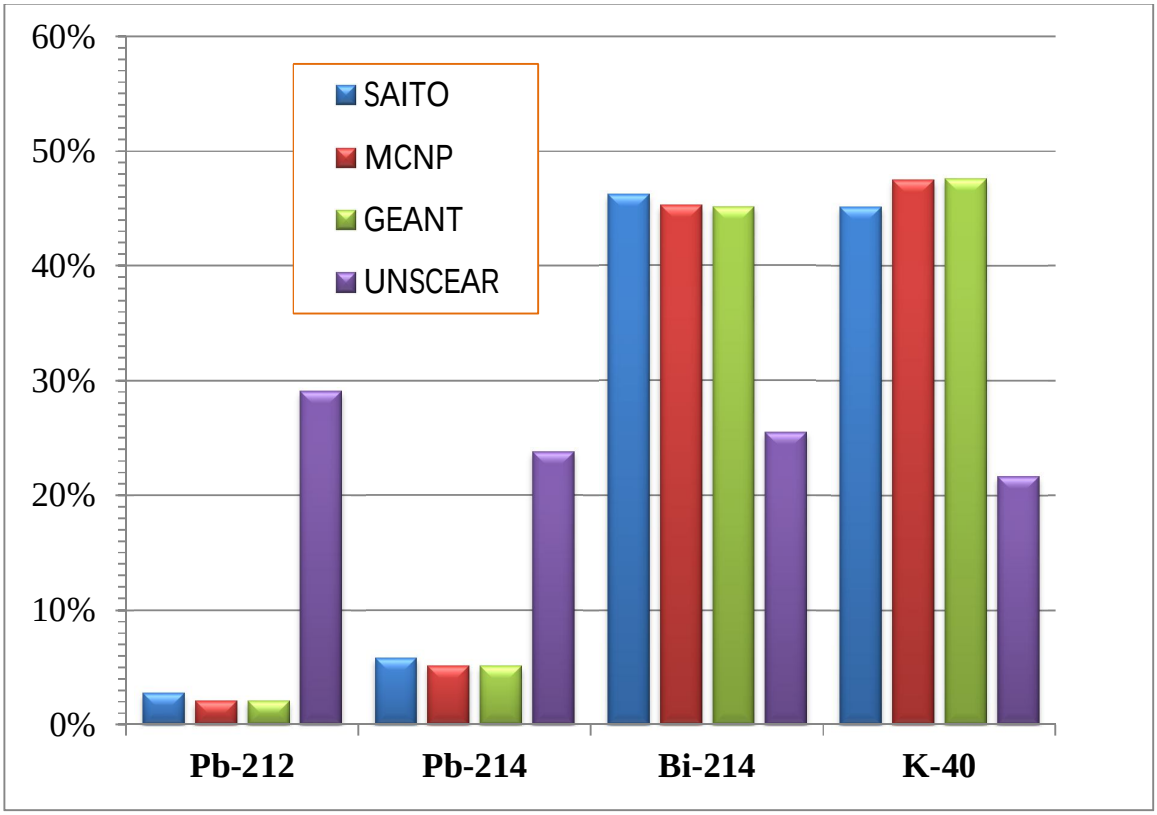

Fig. (4.8): Relative contribution of ^{238}U, ^{232}Th series and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in soil samples

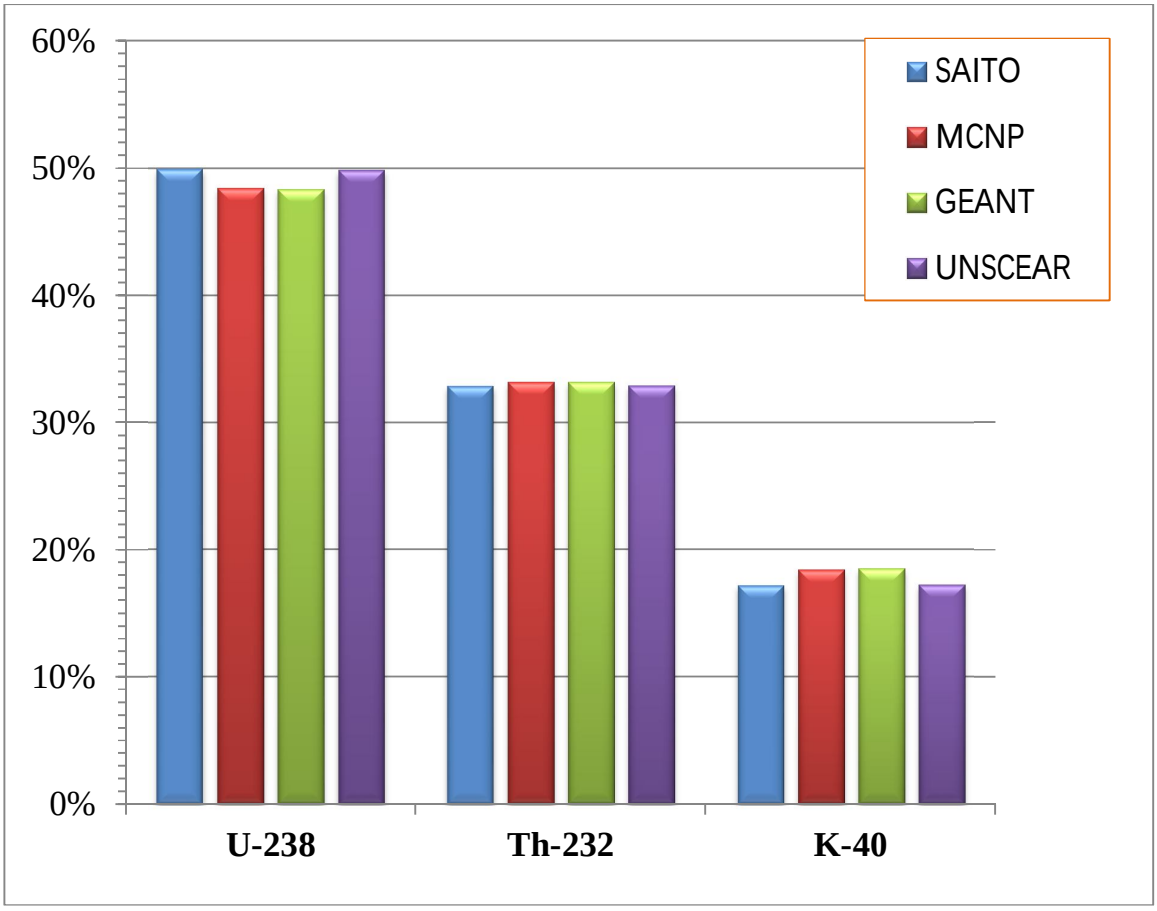

Fig. (4.9): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in rock samples

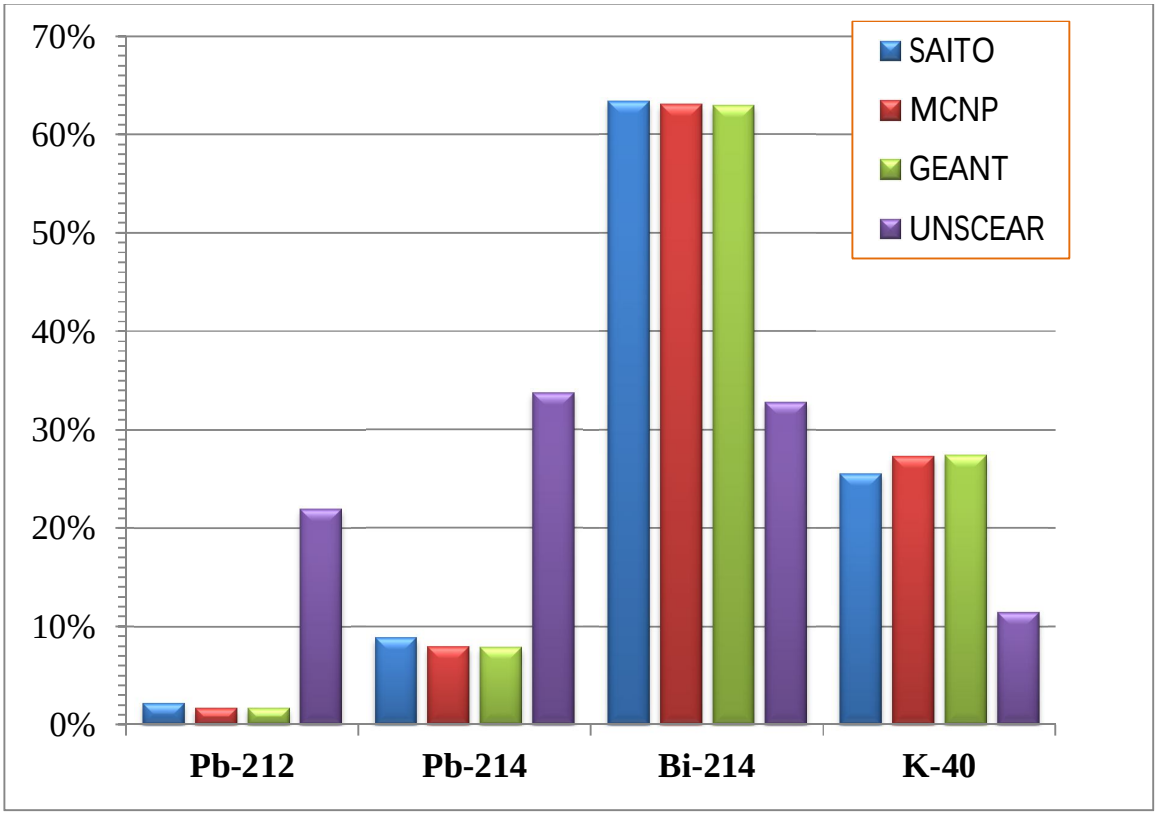

Fig. (4.10): Relative contribution of ^{238}U, ^{232}Th series and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in rock samples

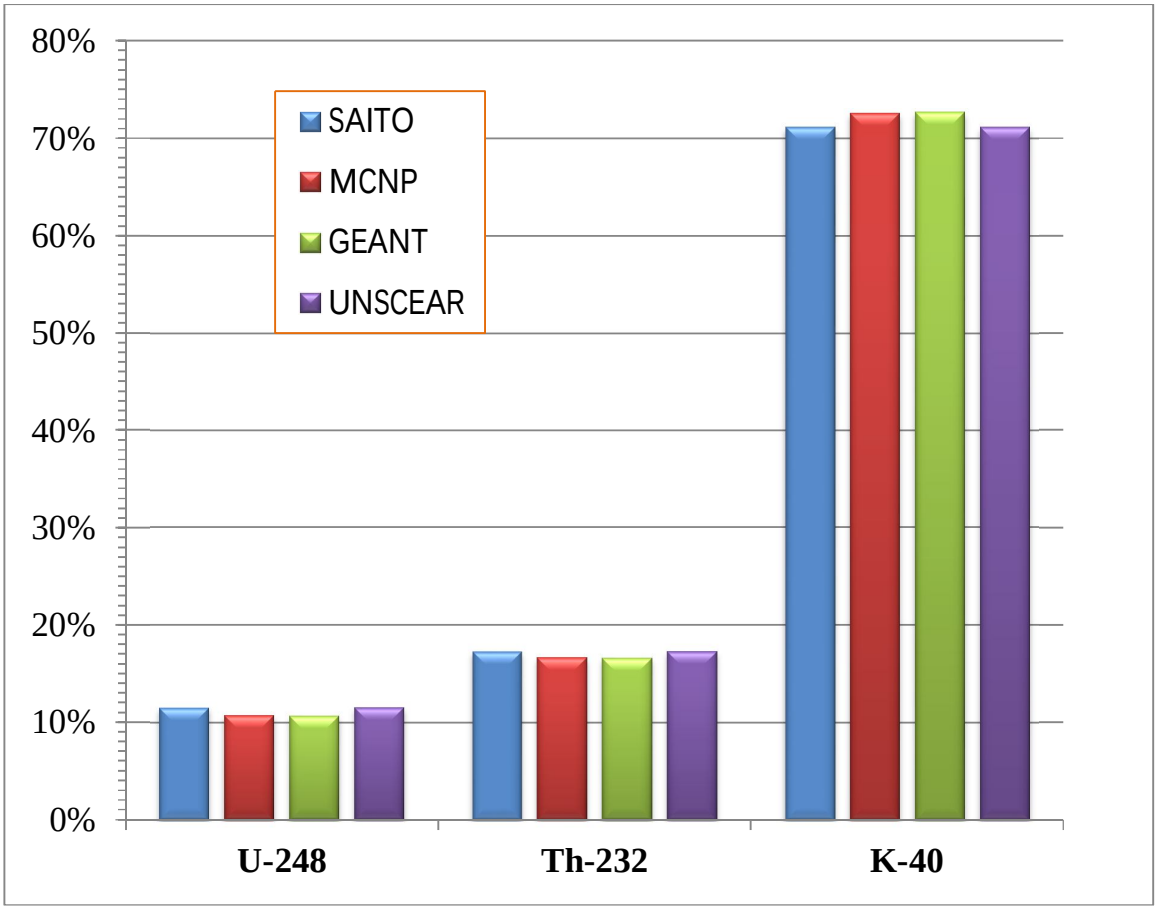

Fig. (4.11): Relative contribution of ^{238}U, ^{232}Th and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in crops samples

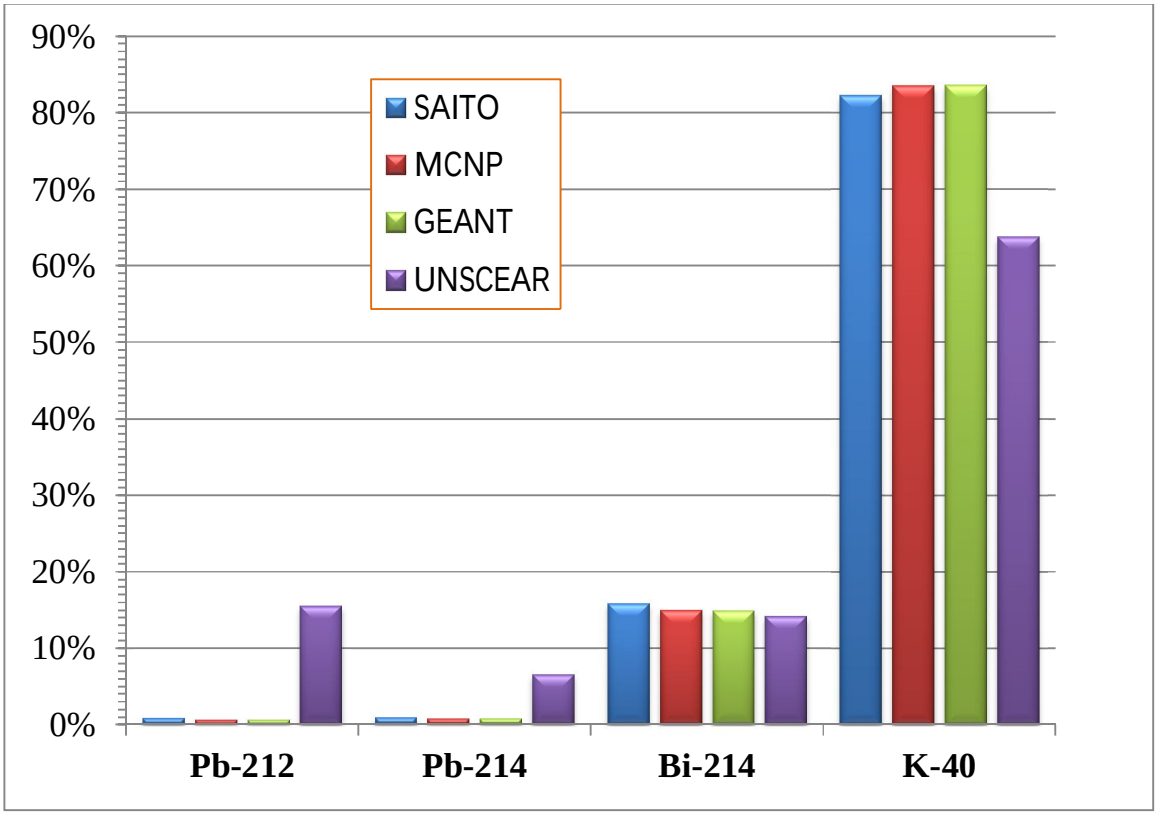

Fig. (4.12): Relative contribution of ^{238}U, ^{232}Th series and ^{40}K to the total absorbed dose rate in air as calculated using different DRCFs in crops samples

4.3 The results of X-ray fluorescence

The heavy metal content in the evaluation in soil, rock and crops samples concentration in p.p.m presented in tables (4.15 to 4.19)

Table (4.15): Heavy metal content in the evaluation in soil samples concentrations in p.p.m.

Sample code	K	Ca	Ti	Mn	Fe	Cu	Rb	Sr	Zr
S1	ND	ND	ND	ND	12800	17	255	351	105
S2	6930	ND	1240	ND	5600	3	69	115	ND
S3	95200	ND	10400	ND	32500	42	743	1170	191
S4	ND	96700	11500	ND	108000	47	906	1630	364
S5	ND	ND	5920	ND	40800	26	398	623	149
S6	ND	ND	882	ND	66200	75	1050	994	213
S7	12000	23900	ND	ND	14200	10	90	345	50
S8	ND	108000	13500	ND	61800	52	610	1430	290
S9	ND	39200	16100	2110	142000	63	913	1260	1040
S10	ND	116000	21700	1430	161000	81	945	1790	647
S11	ND	105000	8450	1480	85200	106	690	1340	924
S12	ND	39700	7830	1060	222000	79	1280	1270	2090
S13	88600	131000	14500	1400	114000	66	1010	1590	1040
S14	86000	106000	16400	1700	190000	76	1460	1760	1210
S15	62300	97300	15100	1160	117000	50	656	786	522
S16	80800	104000	20500	1600	11700	50	716	807	416
S17	82700	91000	11900	27100	50	40	508	552	223
S18	53400	933	10400	ND	28700	44	224	304	264
S19	70600	120000	29900	ND	59700	72	481	662	386
S20	16000	21200	1940	ND	30300	8	101	119	109
S21	71800	113000	21900	ND	202000	102	5510	1340	1090
S22	124000	219000	44300	ND	484000	226	3620	4100	3800
S23	97400	217000	32400	ND	278000	234	1420	1980	1070

Table (4.16): Heavy metal content in the evaluation in soil samples concentrations in p.p.m.

Sample code	K	Ca	Ti	Fe	Cu	Zn	As	Rb	Sr	Zr
S24	55500	86600	15000	33400	45	ND	ND	357	341	466
S25	36000	76900	13700	19000	127	ND	ND	1610	2050	83400
S26	14300	47400	13000	198000	60	ND	ND	1080	980	1340
S27	29700	32900	7150	133000	62	ND	ND	841	1200	319
S28	36500	46500	20500	114000	64	ND	ND	814	1080	449
S29	31800	ND	13700	124000	92	ND	ND	1080	1880	726
S30	59900	ND	8110	236000	140	ND	ND	1380	2050	2130
S31	34000	ND	10300	12	62	ND	ND	692	1200	922
S32	55800	ND	5340	66000	43	ND	ND	819	900	649
S33	41100	ND	8880	188000	64	ND	ND	924	1120	1940
S34	36700	ND	7050	631000	288	ND	ND	2350	2460	1780
S35	45800	73100	11900	258000	82	ND	ND	1990	2450	3790
S36	29200	77400	8080	150000	90	ND	ND	870	1560	1830
S37	ND	11600	1300	46000	10	ND	ND	64	91	17
S38	ND	83000	16100	420000	183	ND	ND	1660	8910	ND
S39	ND	11400	386	30800	5	136	ND	11	464	5
S40	38200	91600	19500	385000	223	1340	ND	1430	5760	ND
S41	ND	8560	2050	9030	6	27	13	ND	133	ND
S42	ND	ND	13700	20	130	618	362	597	1260	404
S43	ND	ND	4420	3380	107	656	415	870	108	769
S44	13400	ND	2480	27600	8	96	16	21	34	15
S45	53600	ND	17000	162000	187	642	264	385	631	376
S46	51000	ND	23400	794000	461	1800	1080	2110	3220	ND
S47	3940	14200	1780	39000	8	34	21	34	87	ND

Table (4.17): Heavy metal content in the evaluation in soil samples concentrations in p.p.m.

Sample code	K	Ca	Ti	Mn	Fe	Cu	Pb	Zn	As	Rb	Sr	Zr	Y
S48	9050	23800	3270	139	19500	6	ND	56	14	23	68	14	ND
S49	56300	119000	22500	1470	115000	73	ND	ND	210	262	759	ND	ND
S50	51500	109000	12200	1190	221000	71	ND	967	149	461	1680	150	ND
S51	ND	ND	1030	637	37300	10	1340	342	ND	ND	149	ND	ND
S52	ND	ND	1390	396	318	7	338	263	ND	ND	ND	ND	ND
S53	ND	70600	8890	906	51900	24	ND	130	357	ND	730	ND	ND
S54	ND	21300	2580	146	25200	6	112	78	ND	ND	96	ND	ND
S55	ND	ND	1240	218	21200	4	201	149	ND	6	13	8	9
S56	ND	15800	2520	472	28100	3	31	28	ND	ND	ND	ND	ND
S57	7860	ND	669	358	22500	8	644	235	ND	ND	123	ND	48
S58	45200	63300	8920	3180	152000	61	467	478	ND	ND	625	ND	ND
S59	4330	5350	622	125	5400	3	47	30	ND	ND	45	ND	ND
S60	ND	7200	501	ND	3710	1	ND	7	ND	ND	30	5	7
S61	ND	ND	ND	ND	55000	ND	ND	ND	ND	ND	449	71	130
S62	ND	ND	ND	ND	14400	8	ND	ND	ND	ND	221	10	42
S63	ND	53100	10400	ND	497000	105	ND	ND	ND	ND	2020	218	296
S64	ND	ND	ND	ND	12700	7	ND	ND	ND	ND	46	2	8
S65	ND	ND	ND	ND	100000	70	ND	ND	ND	ND	581	142	363
S66	ND	ND	ND	ND	81000	43	ND	ND	ND	ND	566	68	119
S67	ND	12200	ND	ND	30200	7	ND	ND	ND	ND	154	12	10
S68	ND	37300	16000	ND	252000	ND	ND	ND	ND	ND	2340	205	297
S69	ND	ND	403	ND	3280	ND	ND	ND	ND	ND	17	3	3

Table (4.18): Heavy metal content in the evaluation in rock samples concentrations in p.p.m.

Sample code	K	Ca	Ti	Mn	Fe	Cu	Pb	Zn	Rb	Sr	Zr	Nb	Y
R70	ND	ND	ND	ND	1870	5	ND	ND	ND	43	3	6	3
R71	2870	3130	674	ND	3160	ND	ND	ND	2	86	10	5	3
R72	ND	15700	2010	ND	1100	27	97	ND	28	459	17	18	ND
R73	30800	23100	3550	ND	19400	39	117	ND	592	1490	86	34	21
R74	32600	52000	5590	ND	180000	10	53	ND	1550	3760	805	407	507
R75	7480	1	871	ND	9950	4	19	ND	56	145	33	19	20
R76	27300	28900	3990	ND	56100	26	157	ND	462	88	185	88	855
R77	56800	74800	8590	ND	273000	119	920	1170	2250	3280	1130	326	394
R78	56500	74100	11300	ND	260000	178		ND	202	874	53	4770	1140
R79	56800	74600	11300	ND	261000	184	1130	ND	2070	5050	1250	491	660
R80	6780	6470	672	ND	8050	3	9	ND	40	85	16	15	15
R81	30200	31500	5260	ND	58900	28	120	ND	597	676	178	92	141
R82	ND	ND	ND	1470	110000	3	ND	846	ND	ND	ND	ND	ND
R83	ND	496000	ND	ND	341	131	482	6280	ND	72200	ND	ND	ND
R84	ND	205000	ND	ND	79300	295	326	9100	658	122000	ND	ND	333
R85	ND	19700	ND	613	110000	15	ND	877	ND	554	ND	ND	ND
R86	ND	286000	ND	ND	25200	170	ND	9270	ND	55400	ND	ND	385
R87	4820	7300	510	1460	115000	4	36	1210	ND	ND	ND	ND	ND
R88	ND	ND	ND	ND	53600	68	208	114	ND	1060	8	ND	29
R89	2890	5340	995	5390	145000	4	35	146	ND	ND	ND	ND	ND
R90	ND	ND	1060	321	87500	6	34	33	15	66	3	ND	3
R91	ND	45000	2310	ND	16200	72	109	2120	ND	3970	11	ND	218

Table (4.19): Heavy metal content in the evaluation in crops samples concentrations in p.p.m.

Sample code	K	Ca	Mn	Fe	Cu	Pb	Zn	Rb	Sr	Zr	Br	Y
C 92	1590	ND	4	23	166	ND	6	3	ND	ND	ND	ND
C 94	3390	2070	8	28	2	1	4	1	ND	1	ND	1
C 95	15000	ND	10	79	4	1	8	14	ND	ND	2	1
C 97	2730	ND	12	601	4	1	14		ND	6	ND	1
C 99	6140	3070	9	286	4	1	12	11	6	ND	ND	ND
C 103	5740	2680	13	60	5	2	18	7	3	1	ND	ND
C 105	3330	1330	ND	485	10	3	32	19	22	ND	4	ND
C 109	43600	9670	ND	1030	9	3	24	66	9	ND	17	ND
C 110	10200	941	ND	109	2	0	7	6	ND	ND	2	ND
C 111	4330	2920	ND	61	2	0	0	5	23	ND	2	ND
C 113	28300	3420	ND	135	4	2	16	14	5	ND	2	ND

4.4 DISCUSSION

Activity concentration of gamma-emitting radionuclides ^{238}U, ^{232}Th and ^{40}K in soil, rock and crops samples from different locations in some areas in South Kordofan State were calculated by using equation (3-1) see tables (4.1, 4.3 and 4.5), and based on secular equilibrium assumption, ^{238}U, ^{232}Th series and ^{40}K concentrations were estimated tables (4.2, 4.4 and 4.6). Statistical summary (mean and range) of ^{238}U, ^{232}Th and ^{40}K were found to be 108.82±112.35 (15.44-868.24), 98.03±97.39 (7.12-406.61) and 1059.13±610.11 (226.67-2168.52) Bq/kg for soil samples, respectively. For rock samples (^{238}U, ^{232}Th and ^{40}K) were found to be 282.76±294.96 (18.64-913.09), 142.79±90.28 (10.87-326.79) and 1081.50±766.05 (90.67-1881.40) Bq/kg, and for crops samples (^{238}U, ^{232}Th ^{40}K) were found to be 12.70±10.81(3.29-34.42), 14.54±10.32(0.47-41.22), and 866.32±574.60(226.67-1681.17) Bq/kg, and which means a predominant concentration of these nuclides see figures(4.1,4.3 and 4.5). A little contamination due to the nuclide ^{137}Cs was encountered, the concentration found was 7.32±10.21 (0.96-19.10) Bq/kg which implies negligible contribution to the total exposure from the environmental background radiation. Fig.(4.5). 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 respectively (UNSCEAR 2000),comparing with obtained results indicate that study areas in South Kordofan State values fall within the range of high background radiation. 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.

The absorbed gamma dose rate in air at a height of 1m from the ground surface was evaluated from the activity concentration using four sets of Dose Rate Conversion Factors (DRCFs) SAITO, 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 SAITO, MCNP, GAINT which 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 using equation (3.2) and the values of DRCFs as illustrated in table (3.7), 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 24). On the other hand, the corresponding annual effective dose was estimated using equation (3.3). Tables (4.7 to 4.12) show a statistical summary of absorbed dose rates in air (nGy/h) in some areas in South 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 (µSv/y). Comparing the results 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 (4.7, 4.9and 4.11) for SATIO and UNSCEAR formulas on one hand as they display values in soil(closed values), rock and crops samples (153.76, 153.65), (262.27, 261.98) and (50.79, 50.78) nGy/h with corresponding annual effective doses of (188.70, 188.56), (321.87, 321.52) and (62.33, 62.32)µSv/y, respectively, whereas Monte Carlo based formulas MCNP and GAINT constitute one family as it is seen from the average values (132.14, 139.14), (222.39, 233.94) and (45.10, 47.60) nGy/h with corresponding annual effective doses of (162.17, 170.75), (272.92, 287.10) and (55.35, 58.41) µSv/y 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., 2003) 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 that highest contribution to the total dose rate from the ^{232}Th as depicted in Fig. (4.7) in soil samples, ^{238}U has the highest contribution to total absorbed dose rate see Fig.(4.9) in rock samples and ^{40}K has the highest contribution to total absorbed dose rate see Fig.(4.11) in crops samples. 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, however, this effect is super imposed 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. For ^{40}K and the ^{232}Th, 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). According to the recent UNSCEAR reports (1993, 2000), 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(5.2). Comparative study of absorbed dose rate in air obtained in this study - calculated on the basis of UNSCEAR DRCFs- is presented in table (5.1) 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), and from different geographical regions (UNSCEAR, 2000). It is apparent that absorbed dose in air and annual effective dose in study areas in South Kordofan State are higher than world-wide average due to UNSCEAR, 2000 the absorbed dose rate from terrestrial gamm rays in normal conditions are approximately 57 nGy/h, while

the global rate annual effective dose is 70μSv/y. The annual effective dose according (ICRP) is lower than the limit 1mSv/y for public exposure (ICRP). See tables (4.13 and 4.14).

In this work X-ray fluorescence (XRF) technique was used to evaluate the soil, rock and crops pollution with heavy metals, the heavy metals (K, Ti, Fe, Cu, Mn, Sr, Zr, Pb and As) in soil samples see tables (4.15 to 4.17.) are above of standard reported by trace elements in soil reference material, (IAEA-Soil-7) that means abundance indicator of this elements in some areas in south kordofan while (Ca, Ni, Zn, Rb, Nb, Br, Y, R and Mo) with standard (soil samples), also for rock samples see table(4.18) this elements (K, Mn, Fe, Cu, Pb, Zn, Rb, Sr, Nb and y) are above of standard. For crops samples see table (4.19) find the elements (Fe, k and Rb) are above with standard.

Table (4.20): Comparision 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 samples	**153.65**
Rock samples	**261.98**
Crops samples	**50.78**
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 (4.21): Areas of high natural radiation background (UNSCEAR 2000)

Country	**Area**	**Absorbed dose rate in air (nGy/ h)**
	Guarapari	90 - 170 (streets) 90 - 90 000 (beaches)
	Mineas Gerais and Goias	110 - 1 300 340 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	200-4000 1800 average
	Ganges delta	260 – 440
Iran	Ramsar	70 - 17 000

	Mahallat	800 - 4 000
Italy	Lazio Campania Orvieto town South Toscana	180 average 200 average 560 average 150 – 200
Niue Island	Pacific	1100 maximum
Switzerland	Tessin, Alps, Jura	100 – 200

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 , 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 , and ^{40}K.
ii. Comparing the calculated absorbed dose rate in air and the corresponding annual effective dose with similar data from different regions in Sudan, studied areas in South Kordofan State falls within the category of high radiation background areas.
iii. The four sets of DRCFs used for estimation of absorbed dose rate have shown unremarkable variation.
iv. Further studies are needed to achieve the goal of establishing data for South Kordofan State.
v. XRF technique has been employed in order to evaluate the pollution of soil, rock and crops samples with trace elements (K, Ca, Ti, Mn, Fe, Ni, Cu, Pb, Zn, As, Rb, Sr, Zr, Nb, Br, Y, R and Mo) in some areas of the South Kordofan State. This is one of the first published studies on soil, rock and crops pollution realized in this region related with the radioactivity. Releases give rise to higher concentrations of the metals relative to the high background values in some locations.

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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 SAITO DRCFs and annual effective dose (µSv/y) in soil samples

Sample code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
S1	Katla	88.19	234.27	87.59	410.05	503.23
S2	Katla	78.85	199.19	88.85	366.89	450.27
S3	Katla	54.43	131.28	74.04	259.76	318.79
S4	Walaey	95.09	183.12	70.26	348.47	427.66
S5	Walaey	52.05	114.53	68.06	234.64	287.96
S6	Walaey	94.15	245.59	90.43	430.17	527.92
S7	Kogoriea	77.02	150.07	66.80	293.89	360.67
S8	Kogoriea	75.69	176.33	71.21	323.22	396.67
S9	Kogoriea	54.78	135.81	41.28	231.86	284.55
S10	El karko	60.78	152.11	74.04	286.93	352.13
S11	El karko	62.30	161.39	70.58	294.26	361.13
S12	El karko	52.24	118.16	69.95	240.34	294.96
S13	El funda	22.97	43.46	68.69	135.11	165.82
S14	El funda	22.39	41.88	69.95	134.22	164.72
S15	El funda	30.79	64.51	69.63	164.94	202.42
S16	El netil	24.77	46.40	67.11	138.28	169.70
S17	El netil	19.45	37.35	65.85	122.65	150.52
S18	El netil	24.50	48.21	57.03	129.74	159.22
S19	Sallara	30.80	66.09	62.70	159.59	195.86
S20	Sallara	38.33	71.75	57.03	167.11	205.08
S21	Sallara	34.64	86.01	64.59	185.25	227.34
S22	Hajer el sultan	28.86	57.95	53.25	140.06	171.88
S23	Hajer el sultan	30.45	50.25	30.56	111.26	136.55
S24	Hajer el sultan	28.61	50.02	27.10	105.73	129.76
S25	El fous	31.32	60.21	51.99	143.52	176.13
S26	El fous	32.49	46.63	58.92	138.03	169.40
S27	El fous	26.91	51.61	63.65	142.17	174.47
S28	Kakara	32.50	83.30	63.65	179.45	220.22
S29	Kakara	33.94	80.13	63.96	178.03	218.48
S30	Kakara	30.95	56.36	67.74	155.05	190.28
S31	Kelara	25.76	48.21	68.06	142.03	174.31
S32	Kelara	21.10	38.48	76.88	136.46	167.47

S33	Kelara	27.59	51.16	69.00	147.75	181.33
S34	Tondiya	42.18	64.06	55.45	161.69	198.44
S35	Tondiya	23.77	41.42	66.17	131.36	161.21
S36	Tondiya	22.12	36.90	66.48	125.50	154.01
S37	Gelogical camp	15.77	17.43	25.21	58.41	71.68
S38	Uro east	113.78	26.71	34.66	175.15	214.95
S39	Uro west	402.00	184.93	ND	586.93	720.30
S40	Uro market	112.04	21.05	28.36	161.45	198.14
S41	Uro middle	43.39	13.35	16.70	73.45	90.14
S42	Dar el-salam school	51.49	17.20	18.59	87.28	107.12
S43	Um takatik	31.99	16.07	17.33	65.39	80.24
S44	Um takatik	19.76	21.28	13.86	54.90	67.37
S45	Um takatik	10.14	4.30	9.45	23.89	29.32
S46	Um takatik(Termites)	22.92	18.79	14.49	56.20	68.97
S47	Kurun	76.14	32.37	ND	108.51	133.17
S48	Kurun hill	30.56	19.92	17.64	68.12	83.60
S49	Kurun	94.47	19.92	17.64	132.03	162.04
S50	Kurun	14.56	14.26	17.96	46.78	57.41
S51	Abu galaha	14.39	12.68	19.53	46.60	57.19
S52	Tumluk hill	40.09	16.75	32.77	89.61	109.97
S53	Tumluk hill	40.62	19.92	31.82	92.36	113.35
S54	Tumluk	36.58	15.39	28.04	80.01	98.19
S55	Aryab camp	16.49	14.03	21.11	51.64	63.37
S56	Aryab (trench)	8.50	8.83	33.71	51.04	62.64
S57	Aryab	26.84	12.00	29.62	68.45	84.01
S58	Uro hill height	98.16	25.13	50.10	173.38	212.78
S59	Near Uro village	94.85	20.15	44.43	159.42	195.65
S60	Near Uro hill	76.23	17.43	22.37	116.03	142.40
S61	Uro village	100.81	29.65	ND	130.46	160.11
S62	Uro village	9.24	22.86	ND	32.10	39.39
S63	Tirmi stream	41.52	16.98	20.48	78.98	96.92
S64	Stream between Tirmi and Uro	37.32	13.35	45.37	96.04	117.87
S65	Western north of Uro	55.02	18.79	20.17	93.97	115.33
S66	El layoon farm	118.54	22.86	33.40	174.80	214.52
S67	El layoon village	7.70	13.35	23.32	44.37	54.45
S68	El layoon	7.15	9.96	20.80	37.90	46.51

S69	El layoon	74.55	23.54	ND	98.09	120.38
Mean		50.38	59.21	44.17	153.76	188.70
SD		52.02	58.83	25.44	104.28	127.97
Min		7.15	4.30	9.45	23.89	29.32
Max		402.00	245.59	90.43	586.93	720.30

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

Sample code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff.Dose
S1	Katla	72.55	200.44	79.40	352.40	432.48
S2	Katla	64.87	170.43	80.54	315.84	387.61
S3	Katla	44.78	112.33	67.12	224.23	275.18
S4	Walaey	78.23	156.68	63.69	298.60	366.45
S5	Walaey	42.82	98.00	61.69	202.51	248.53
S6	Walaey	77.46	210.13	81.97	369.56	453.53
S7	Kogoriea	63.37	128.40	60.55	252.32	309.65
S8	Kogoriea	62.27	150.87	64.55	277.68	340.78
S9	Kogoriea	45.06	116.20	37.41	198.68	243.83
S10	El karko	5ND	130.14	67.12	247.26	303.45
S11	El karko	51.25	138.08	63.98	253.31	310.88
S12	El karko	42.98	101.09	63.41	207.48	254.62
S13	El funda	18.90	37.18	62.26	118.34	145.24
S14	El funda	18.42	35.83	63.41	117.66	144.39
S15	El funda	25.33	55.19	63.12	143.65	176.29
S16	El netil	20.38	39.70	60.84	120.91	148.39
S17	El netil	16.00	31.95	59.69	107.65	132.11
S18	El netil	20.15	41.25	51.70	113.10	138.80
S19	Sallara	25.34	56.55	56.84	138.73	170.25
S20	Sallara	31.53	61.39	51.70	144.62	177.48
S21	Sallara	28.50	73.59	58.55	160.64	197.15
S22	Hajer el sultan	23.75	49.58	48.27	121.59	149.22
S23	Hajer el sultan	25.05	42.99	27.70	95.75	117.51
S24	Hajer el sultan	23.54	42.80	24.56	90.90	111.56
S25	El fous	25.77	51.52	47.13	124.41	152.68
S26	El fous	26.73	39.90	53.41	120.03	147.31
S27	El fous	22.14	44.16	57.69	123.99	152.16
S28	Kakara	26.74	71.27	57.69	155.70	191.08
S29	Kakara	27.92	68.56	57.98	154.46	189.56
S30	Kakara	25.46	48.22	61.41	135.09	165.79
S31	Kelara	21.20	41.25	61.69	124.14	152.35
S32	Kelara	17.36	32.92	69.69	119.97	147.23

S33	Kelara	22.70	43.77	62.55	129.02	158.34
S34	Tondiya	34.70	54.81	50.27	139.78	171.54
S35	Tondiya	19.56	35.44	59.98	114.98	141.11
S36	Tondiya	18.20	31.57	60.26	110.03	135.03
S37	Gelogical camp	12.98	14.91	22.85	50.74	62.27
S38	Uro east	93.61	22.85	31.42	147.88	181.49
S39	Uro west	330.73	158.23	ND	488.96	600.07
S40	Uro market	92.18	18.01	25.70	135.89	166.78
S41	Uro middle	35.70	11.43	15.14	62.27	76.41
S42	Dar el-salam school	42.36	14.72	16.85	73.93	90.73
S43	Um takatik	26.31	13.75	15.71	55.77	68.45
S44	Um takatik	16.26	18.20	12.57	47.03	57.71
S45	Um takatik	8.34	3.68	8.57	20.59	25.27
S46	Um takatik(Termites)	18.86	16.07	13.14	48.07	58.99
S47	Kurun	62.64	27.69	ND	90.34	110.86
S48	Kurun hill	25.14	17.04	15.99	58.18	71.40
S49	Kurun	77.72	17.04	15.99	110.76	135.93
S50	Kurun	11.98	12.20	16.28	40.46	49.66
S51	Abu galaha	11.84	10.85	17.71	40.39	49.57
S52	Tumluk hill	32.98	14.33	29.70	77.02	94.52
S53	Tumluk hill	33.42	17.04	28.85	79.31	97.33
S54	Tumluk	30.09	13.17	25.42	68.68	84.29
S55	Aryab camp	13.57	12.01	19.14	44.71	54.87
S56	Aryab (trench)	7.00	7.55	30.56	45.11	55.36
S57	Aryab	22.08	10.26	26.85	59.19	72.64
S58	Uro hill height	80.75	21.50	45.41	147.66	181.22
S59	Near Uro village	78.04	17.24	40.27	135.54	166.34
S60	Near Uro hill	62.72	14.91	20.28	97.91	120.15
S61	Uro village	82.94	25.37	ND	108.31	132.92
S62	Uro village	7.60	19.56	ND	27.16	33.33
S63	Tirmi stream	34.16	14.52	18.56	67.25	82.53
S64	Stream between Tirmi and Uro	30.70	11.43	41.13	83.26	102.18
S65	Western north of Uro	45.27	16.07	18.28	79.62	97.71
S66	El layoon farm	97.52	19.56	30.27	147.36	180.84
S67	El layoon village	6.33	11.43	21.14	38.90	47.73
S68	El layoon	5.88	8.52	18.85	33.25	40.81

S69	El layoon	61.34	20.14	ND	81.48	99.99
Mean		41.45	50.66	40.04	132.14	162.17
SD		42.80	50.33	23.06	88.72	108.88
Min		5.88	3.68	8.57	20.59	25.27
Max		330.73	210.13	81.97	488.96	600.07

Table (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

Sample code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff.Dose
S1	Katla	76.18	210.90	83.92	370.99	455.30
S2	Katla	68.12	179.31	85.12	332.55	408.12
S3	Katla	47.02	118.18	70.94	236.14	289.80
S4	Walaey	82.14	164.85	67.31	314.30	385.72
S5	Walaey	44.96	103.11	65.20	213.27	261.73
S6	Walaey	81.33	221.09	86.63	389.05	477.46
S7	Kogoriea	66.53	135.10	63.99	265.63	325.99
S8	Kogoriea	65.38	158.73	68.22	292.33	358.76
S9	Kogoriea	47.32	122.26	39.54	209.12	256.64
S10	El karko	52.50	136.93	70.94	260.37	319.53
S11	El karko	53.82	145.29	67.62	266.72	327.32
S12	El karko	45.13	106.37	67.01	218.50	268.16
S13	El funda	19.84	39.12	65.80	124.77	153.12
S14	El funda	19.35	37.70	67.01	124.05	152.24
S15	El funda	26.60	58.07	66.71	151.38	185.78
S16	El netil	21.39	41.77	64.30	127.46	156.43
S17	El netil	16.80	33.62	63.09	113.51	139.30
S18	El netil	21.16	43.40	54.64	119.20	146.28
S19	Sallara	26.61	59.50	60.07	146.17	179.39
S20	Sallara	33.11	64.59	54.64	152.34	186.95
S21	Sallara	29.93	77.43	61.88	169.24	207.69
S22	Hajer el sultan	24.93	52.16	51.01	128.11	157.22
S23	Hajer el sultan	26.31	45.24	29.28	100.82	123.73
S24	Hajer el sultan	24.71	45.03	25.96	95.71	117.45
S25	El fous	27.05	54.20	49.81	131.06	160.84
S26	El fous	28.06	41.98	56.45	126.49	155.23
S27	El fous	23.25	46.46	60.97	130.68	160.38
S28	Kakara	28.08	74.99	60.97	164.04	201.31
S29	Kakara	29.32	72.13	61.28	162.73	199.70
S30	Kakara	26.73	50.74	64.90	142.37	174.72
S31	Kelara	22.26	43.40	65.20	130.86	160.60
S32	Kelara	18.23	34.64	73.65	126.52	155.27

S33	Kelara	23.84	46.05	66.11	135.99	166.90
S34	Tondiya	36.44	57.67	53.13	147.23	180.69
S35	Tondiya	20.54	37.29	63.39	121.22	148.76
S36	Tondiya	19.11	33.21	63.69	116.01	142.38
S37	Gelogical camp	13.62	15.69	24.15	53.46	65.61
S38	Uro east	98.29	24.04	33.20	155.54	190.89
S39	Uro west	347.26	166.48	ND	513.74	630.48
S40	Uro market	96.79	18.95	27.17	142.90	175.38
S41	Uro middle	37.49	12.02	16.00	65.51	80.39
S42	Dar el-salam school	44.48	15.49	17.81	77.78	95.45
S43	Um takatik	27.63	14.47	16.60	58.70	72.04
S44	Um takatik	17.07	19.15	13.28	49.50	60.75
S45	Um takatik	8.76	3.87	9.06	21.68	26.61
S46	Um takatik(Termites)	19.80	16.91	13.89	50.60	62.09
S47	Kurun	65.77	29.14	ND	94.91	116.48
S48	Kurun hill	26.40	17.93	16.90	61.23	75.15
S49	Kurun	81.61	17.93	16.90	116.44	142.90
S50	Kurun	12.58	12.84	17.21	42.62	52.31
S51	Abu galaha	12.43	11.41	18.72	42.56	52.23
S52	Tumluk hill	34.63	15.08	31.39	81.10	99.53
S53	Tumluk hill	35.09	17.93	30.49	83.51	102.49
S54	Tumluk	31.60	13.86	26.87	72.32	88.75
S55	Aryab camp	14.25	12.63	20.22	47.11	57.81
S56	Aryab (trench)	7.35	7.95	32.30	47.59	58.41
S57	Aryab	23.19	10.80	28.37	62.36	76.53
S58	Uro hill height	84.79	22.62	48.00	155.40	190.72
S59	Near Uro village	81.94	18.14	42.56	142.63	175.05
S60	Near Uro hill	65.85	15.69	21.43	102.97	126.37
S61	Uro village	87.08	26.69	ND	113.78	139.63
S62	Uro village	7.98	20.58	ND	28.56	35.05
S63	Tirmi stream	35.87	15.28	19.62	70.77	86.85
S64	Stream between Tirmi and Uro	32.24	12.02	43.47	87.73	107.66
S65	Western north of Uro	47.53	16.91	19.32	83.76	102.79
S66	El layoon farm	102.40	20.58	32.00	154.97	190.19
S67	El layoon village	6.65	12.02	22.34	41.01	50.33
S68	El layoon	6.17	8.97	19.92	35.06	43.03
S69	El layoon	64.40	21.19	ND	85.59	105.04

Mean	43.52	53.30	42.31	139.14	170.75
SD	44.94	52.96	24.37	93.34	114.55
Min	6.17	3.87	9.06	21.68	26.61
Max	347.26	221.09	86.63	513.74	630.48

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

Sample code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff.Dose
S1	Katla	88.00	234.27	87.59	409.86	503.00
S2	Katla	78.68	199.19	88.85	366.72	450.06
S3	Katla	54.32	131.28	74.04	259.64	318.65
S4	Walaey	94.88	183.12	70.26	348.26	427.40
S5	Walaey	51.94	114.53	68.06	234.53	287.82
S6	Walaey	93.95	245.59	90.43	429.96	527.67
S7	Kogoriea	76.86	150.07	66.80	293.72	360.47
S8	Kogoriea	75.52	176.33	71.21	323.06	396.47
S9	Kogoriea	54.66	135.81	41.28	231.74	284.41
S10	El karko	60.64	152.11	74.04	286.80	351.97
S11	El karko	62.16	161.39	70.58	294.13	360.97
S12	El karko	52.13	118.16	69.95	240.23	294.82
S13	El funda	22.92	43.46	68.69	135.07	165.76
S14	El funda	22.35	41.88	69.95	134.17	164.66
S15	El funda	30.73	64.51	69.63	164.87	202.33
S16	El netil	24.71	46.40	67.11	138.23	169.64
S17	El netil	19.41	37.35	65.85	122.61	150.47
S18	El netil	24.44	48.21	57.03	129.68	159.15
S19	Sallara	30.73	66.09	62.70	159.53	195.78
S20	Sallara	38.24	71.75	57.03	167.03	204.98
S21	Sallara	34.57	86.01	64.59	185.17	227.25
S22	Hajer el sultan	28.80	57.95	53.25	14ND	171.81
S23	Hajer el sultan	30.39	50.25	30.56	111.20	136.47
S24	Hajer el sultan	28.55	50.02	27.10	105.67	129.68
S25	El fous	31.25	60.21	51.99	143.45	176.04
S26	El fous	32.42	46.63	58.92	137.96	169.32
S27	El fous	26.85	51.61	63.65	142.11	174.40
S28	Kakara	32.43	83.30	63.65	179.38	220.14
S29	Kakara	33.86	80.13	63.96	177.95	218.39
S30	Kakara	30.88	56.36	67.74	154.98	190.20
S31	Kelara	25.71	48.21	68.06	141.98	174.24
S32	Kelara	21.05	38.48	76.88	136.41	167.41

S33	Kelara	27.54	51.16	69.00	147.69	181.25
S34	Tondiya	42.09	64.06	55.45	161.60	198.32
S35	Tondiya	23.72	41.42	66.17	131.31	161.15
S36	Tondiya	22.07	36.90	66.48	125.45	153.95
S37	Gelogical camp	15.74	17.43	25.21	58.37	71.64
S38	Uro east	113.54	26.71	34.66	174.91	214.65
S39	Uro west	401.13	184.93	ND	586.06	719.23
S40	Uro market	111.80	21.05	28.36	161.21	197.84
S41	Uro middle	43.30	13.35	16.70	73.35	90.02
S42	Dar el-salam school	51.38	17.20	18.59	87.17	106.98
S43	Um takatik	31.92	16.07	17.33	65.32	80.16
S44	Um takatik	19.72	21.28	13.86	54.86	67.32
S45	Um takatik	10.11	4.30	9.45	23.87	29.29
S46	Um takatik(Termites)	22.87	18.79	14.49	56.15	68.91
S47	Kurun	75.98	32.37	ND	108.34	132.96
S48	Kurun hill	30.49	19.92	17.64	68.05	83.52
S49	Kurun	94.27	19.92	17.64	131.83	161.79
S50	Kurun	14.53	14.26	17.96	46.75	57.38
S51	Abu galaha	14.36	12.68	19.53	46.57	57.16
S52	Tumluk hill	4ND	16.75	32.77	89.52	109.87
S53	Tumluk hill	40.53	19.92	31.82	92.27	113.24
S54	Tumluk	36.50	15.39	28.04	79.93	98.10
S55	Aryab camp	16.46	14.03	21.11	51.60	63.33
S56	Aryab (trench)	8.49	8.83	33.71	51.03	62.62
S57	Aryab	26.78	12.00	29.62	68.40	83.94
S58	Uro hill height	97.94	25.13	50.10	173.17	212.52
S59	Near Uro village	94.65	20.15	44.43	159.22	195.40
S60	Near Uro hill	76.06	17.43	22.37	115.86	142.19
S61	Uro village	100.59	29.65	ND	130.24	159.84
S62	Uro village	9.22	22.86	ND	32.08	39.37
S63	Tirmi stream	41.43	16.98	20.48	78.89	96.81
S64	Stream between Tirmi and Uro	37.24	13.35	45.37	95.96	117.77
S65	Western north of Uro	54.90	18.79	20.17	93.85	115.18
S66	El layoon farm	118.28	22.86	33.40	174.54	214.20
S67	El layoon village	7.68	13.35	23.32	44.35	54.43
S68	El layoon	7.13	9.96	20.80	37.89	46.50

S69	El layoon	74.39	23.54	ND	97.93	120.19
Mean		50.27	59.21	44.17	153.65	188.56
SD		51.91	58.83	25.44	104.20	127.87
Min		7.13	4.30	9.45	23.87	29.29
Max		401.13	245.59	90.43	586.06	719.23

Table (5): 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 SAITO DRCFs and annual effective dose (µSv/y) in soil samples

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose Rate	Ann. Eff. Dose
S1	Katla	10.74	8.83	87.94	87.59	195.10	239.43
S2	Katla	9.14	7.96	78.13	88.85	184.08	225.91
S3	Katla	6.02	5.53	53.64	74.04	139.24	170.88
S4	Walaey	8.40	10.98	84.07	70.26	173.71	213.18
S5	Walaey	5.25	5.53	49.51	68.05	128.35	157.52
S6	Walaey	11.26	9.42	93.87	90.43	204.98	251.56
S7	Kogoriea	6.88	8.83	68.60	66.80	151.10	185.44
S8	Kogoriea	8.09	7.81	73.75	71.21	160.86	197.41
S9	Kogoriea	6.23	5.48	54.67	41.28	107.65	132.11
S10	El karko	6.98	6.22	59.57	74.04	146.81	180.17
S11	El karko	7.40	6.58	59.57	70.58	144.13	176.88
S12	El karko	5.42	5.68	48.74	69.95	129.79	159.28
S13	El funda	1.99	2.57	20.89	68.69	94.14	115.53
S14	El funda	1.92	2.54	20.11	69.95	94.53	116.00
S15	El funda	2.96	3.47	27.85	69.63	103.91	127.52
S16	El netil	2.13	2.96	21.14	67.11	93.35	114.56
S17	El netil	1.71	2.09	18.31	65.85	87.97	107.96
S18	El netil	2.21	2.72	22.44	57.03	84.40	103.58
S19	Sallara	3.03	3.26	29.40	62.70	98.39	120.75
S20	Sallara	3.29	4.16	35.85	57.03	100.32	123.12
S21	Sallara	3.94	3.50	34.30	64.59	106.33	130.50
S22	Hajer el sultan	2.66	3.26	26.04	53.25	85.21	104.58
S23	Hajer el sultan	2.30	3.53	26.82	30.56	63.22	77.58
S24	Hajer el sultan	2.29	3.20	26.04	27.10	58.64	71.96
S25	El fous	2.76	3.77	26.56	51.99	85.08	104.41
S26	El fous	2.14	3.80	28.37	58.92	93.22	114.41
S27	El fous	2.37	3.08	23.98	63.65	93.08	114.23
S28	Kakara	3.82	3.17	33.01	63.65	103.64	127.20
S29	Kakara	3.67	3.65	31.98	63.96	103.26	126.73
S30	Kakara	2.58	3.26	29.65	67.74	103.24	126.70
S31	Kelara	2.21	3.02	22.44	68.06	95.73	117.48
S32	Kelara	1.76	2.48	18.31	76.88	99.44	122.03

S33	Kelara	2.35	2.96	26.04	69.00	100.36	123.16
S34	Tondiya	2.94	4.79	37.91	55.45	101.09	124.06
S35	Tondiya	1.90	2.69	21.41	66.17	92.16	113.11
S36	Tondiya	1.69	2.51	19.86	66.48	90.54	111.12
S37	Gelogical camp	0.80	2.03	12.38	25.21	40.42	49.60
S38	Uro east	1.22	15.11	86.13	34.66	137.12	168.28
S39	Uro west	8.48	37.37	421.88	ND	467.73	574.02
S40	Uro market	0.97	14.24	89.48	28.36	133.05	163.28
S41	Uro middle	0.61	5.56	34.30	16.70	57.17	70.17
S42	Dar el-salam school	0.79	6.70	39.97	18.59	66.05	81.06
S43	Um takatik	0.74	4.28	23.98	17.33	46.33	56.86
S44	Um takatik	0.98	2.48	15.99	13.86	33.31	40.88
S45	Um takatik	0.20	1.20	8.77	9.45	19.61	24.07
S46	Um takatik(Termite)	0.86	2.84	18.82	14.49	37.02	45.43
S47	Kurun	1.48	9.21	64.21	ND	74.91	91.93
S48	Kurun hill	0.91	3.59	26.56	17.64	48.71	59.78
S49	Kurun	0.91	11.82	76.85	17.64	107.22	131.59
S50	Kurun	0.65	1.85	11.60	17.96	32.07	39.36
S51	Abu galaha	0.58	1.88	11.09	19.53	33.09	40.61
S52	Tumluk hill	0.77	5.00	32.75	32.77	71.28	87.48
S53	Tumluk hill	0.91	5.09	33.01	31.82	70.83	86.92
S54	Tumluk	0.71	4.31	31.72	28.04	64.77	79.49
S55	Aryab camp	0.64	2.06	13.41	21.11	37.23	45.69
S56	Aryab (trench)	0.40	0.99	7.48	33.71	42.58	52.26
S57	Aryab	0.55	3.38	21.66	29.62	55.21	67.76
S58	Uro hill height	1.15	12.48	78.39	50.10	142.12	174.41
S59	Near Uro village	0.92	11.91	76.85	44.43	134.11	164.58
S60	Near Uro hill	0.80	9.90	59.31	22.37	92.38	113.38
S61	Uro village	1.36	12.72	81.23	ND	95.31	116.96
S62	Uro village	1.05	0.60	11.60	ND	13.25	16.26
S63	Tirmi stream	0.78	4.88	36.10	20.48	62.24	76.38
S64	Stream between Tirmi and Uro	0.61	4.52	31.46	45.37	81.97	100.59
S65	Western north of Uro	0.86	6.76	45.65	20.16	73.43	90.12
S66	El layoon farm	1.05	13.91	103.15	33.40	151.51	185.94
S67	El layoon village	0.61	0.87	6.96	23.32	31.76	38.97
S68	El layoon	0.46	0.81	6.42	20.79	28.48	34.95

S69	El layoon	1.08	9.75	57.51	ND	68.34	83.87
Mean		2.72	5.73	45.18	44.17	97.79	120.01
SD		2.70	5.27	52.46	25.44	62.23	76.37
Min		0.20	0.60	6.42	9.45	13.25	16.26
Max		11.26	37.37	421.88	90.43	467.73	574.02

Table (6): 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

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose Rate	Ann. Eff. Dose
S1	Katla	6.97	6.71	74.23	79.40	167.30	205.32
S2	Katla	5.92	6.05	65.95	80.54	158.47	194.48
S3	Katla	3.90	4.21	45.28	67.12	120.51	147.89
S4	Walaey	5.45	8.35	70.96	63.69	148.44	182.18
S5	Walaey	3.41	4.21	41.79	61.69	111.10	136.34
S6	Walaey	7.30	7.16	79.23	81.97	175.67	215.59
S7	Kogoriea	4.46	6.71	57.90	60.55	129.62	159.08
S8	Kogoriea	5.24	5.94	62.26	64.55	137.98	169.34
S9	Kogoriea	4.04	4.16	46.15	37.41	91.76	112.61
S10	El karko	4.52	4.73	50.28	67.12	126.65	155.44
S11	El karko	4.80	5.00	50.28	63.98	124.06	152.25
S12	El karko	3.51	4.32	41.14	63.41	112.38	137.92
S13	El funda	1.29	1.96	17.63	62.26	83.14	102.04
S14	El funda	1.25	1.93	16.98	63.41	83.56	102.55
S15	El funda	1.92	2.64	23.51	63.12	91.18	111.90
S16	El netil	1.38	2.25	17.85	60.83	82.32	101.02
S17	El netil	1.11	1.59	15.46	59.69	77.85	95.54
S18	El netil	1.43	2.07	18.94	51.70	74.14	90.98
S19	Sallara	1.97	2.48	24.81	56.84	86.10	105.66
S20	Sallara	2.13	3.16	30.26	51.70	87.25	107.07
S21	Sallara	2.56	2.66	28.95	58.55	92.72	113.79
S22	Hajer el sultan	1.72	2.48	21.98	48.27	74.46	91.37
S23	Hajer el sultan	1.49	2.68	22.64	27.70	54.52	66.91
S24	Hajer el sultan	1.49	2.43	21.98	24.56	50.47	61.94
S25	El fous	1.79	2.87	22.42	47.13	74.20	91.06
S26	El fous	1.39	2.89	23.94	53.41	81.63	100.18
S27	El fous	1.53	2.34	20.25	57.69	81.82	100.41
S28	Kakara	2.48	2.41	27.86	57.69	90.44	110.99
S29	Kakara	2.38	2.77	26.99	57.98	90.13	110.61
S30	Kakara	1.68	2.48	25.03	61.41	90.59	111.18
S31	Kelara	1.43	2.30	18.94	61.69	84.36	103.53
S32	Kelara	1.14	1.89	15.46	69.69	88.18	108.21

S33	Kelara	1.52	2.25	21.98	62.55	88.31	108.37
S34	Tondiya	1.90	3.64	32.00	50.27	87.81	107.76
S35	Tondiya	1.23	2.05	18.07	59.98	81.33	99.81
S36	Tondiya	1.10	1.91	16.76	60.26	80.03	98.22
S37	Gelogical camp	0.52	1.55	10.45	22.85	35.36	43.40
S38	Uro east	0.79	11.48	72.70	31.42	116.40	142.85
S39	Uro west	5.50	28.40	356.12	ND	390.02	478.65
S40	Uro market	0.63	10.82	75.53	25.70	112.69	138.30
S41	Uro middle	0.40	4.23	28.95	15.14	48.72	59.79
S42	Dar el-salam school	0.51	5.09	33.74	16.85	56.20	68.97
S43	Um takatik	0.48	3.25	20.25	15.71	39.68	48.70
S44	Um takatik	0.63	1.89	13.50	12.57	28.58	35.08
S45	Um takatik	0.13	0.91	7.40	8.57	17.01	20.87
S46	Um takatik(Termite)	0.56	2.16	15.89	13.14	31.75	38.96
S47	Kurun	0.96	7.00	54.20	ND	62.17	76.30
S48	Kurun hill	0.59	2.73	22.42	15.99	41.74	51.22
S49	Kurun	0.59	8.98	64.87	15.99	90.44	110.99
S50	Kurun	0.42	1.41	9.80	16.28	27.91	34.25
S51	Abu galaha	0.38	1.43	9.36	17.71	28.88	35.44
S52	Tumluk hill	0.50	3.80	27.64	29.70	61.64	75.65
S53	Tumluk hill	0.59	3.87	27.86	28.85	61.17	75.07
S54	Tumluk	0.46	3.27	26.77	25.42	55.92	68.63
S55	Aryab camp	0.42	1.57	11.32	19.14	32.44	39.81
S56	Aryab (trench)	0.26	0.75	6.31	30.56	37.89	46.50
S57	Aryab	0.36	2.57	18.29	26.85	48.06	58.98
S58	Uro hill height	0.75	9.48	66.17	45.41	121.81	149.49
S59	Near Uro village	0.60	9.05	64.87	40.27	114.79	140.87
S60	Near Uro hill	0.52	7.53	50.07	20.28	78.39	96.20
S61	Uro village	0.88	9.66	68.57	ND	79.11	97.09
S62	Uro village	0.68	0.45	9.80	ND	10.93	13.41
S63	Tirmi stream	0.50	3.71	30.47	18.56	53.25	65.35
S64	Stream between Tirmi and Uro	0.40	3.43	26.56	41.13	71.52	87.77
S65	Western north of Uro	0.56	5.14	38.53	18.28	62.51	76.71
S66	El layoon farm	0.68	10.57	87.07	30.27	128.60	157.82
S67	El layoon village	0.40	0.66	5.88	21.14	28.07	34.45
S68	El layoon	0.30	0.61	5.42	18.85	25.18	30.90

S69	El layoon	0.70	7.41	48.54	ND	56.66	69.53
Mean		1.76	4.36	38.14	40.04	84.29	103.44
SD		1.75	4.01	44.29	23.06	52.34	64.23
Min		0.13	0.45	5.42	8.57	10.93	13.41
Max		7.30	28.40	356.12	81.97	390.02	478.65

Table (7): 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 GEANT DRCFs and annual effective dose (µSv/y) in soil samples

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose Rate	Ann. Eff. Dose
S1	Katla	7.44	7.02	77.97	83.92	176.34	216.41
S2	Katla	6.32	6.33	69.28	85.12	167.05	205.01
S3	Katla	4.17	4.40	47.56	70.94	127.06	155.93
S4	Walaey	5.81	8.73	74.54	67.31	156.39	191.93
S5	Walaey	3.64	4.40	43.90	65.20	117.13	143.75
S6	Walaey	7.79	7.49	83.22	86.63	185.15	227.22
S7	Kogoriea	4.76	7.02	60.82	63.99	136.59	167.63
S8	Kogoriea	5.60	6.21	65.39	68.22	145.42	178.46
S9	Kogoriea	4.31	4.35	48.47	39.54	96.68	118.65
S10	El karko	4.83	4.95	52.82	70.94	133.53	163.87
S11	El karko	5.12	5.23	52.82	67.62	130.79	160.51
S12	El karko	3.75	4.52	43.21	67.01	118.49	145.42
S13	El funda	1.38	2.05	18.52	65.80	87.75	107.69
S14	El funda	1.33	2.02	17.83	67.01	88.20	108.24
S15	El funda	2.05	2.76	24.69	66.71	96.21	118.07
S16	El netil	1.47	2.36	18.75	64.30	86.87	106.61
S17	El netil	1.19	1.67	16.23	63.09	82.17	100.85
S18	El netil	1.53	2.16	19.89	54.64	78.22	96.00
S19	Sallara	2.10	2.59	26.06	60.07	90.83	111.46
S20	Sallara	2.28	3.31	31.78	54.64	92.00	112.91
S21	Sallara	2.73	2.78	30.41	61.88	97.80	120.03
S22	Hajer el sultan	1.84	2.59	23.09	51.01	78.54	96.39
S23	Hajer el sultan	1.59	2.81	23.78	29.28	57.46	70.52
S24	Hajer el sultan	1.59	2.55	23.09	25.96	53.19	65.27
S25	El fous	1.91	3.00	23.55	49.81	78.27	96.05
S26	El fous	1.48	3.02	25.15	56.45	86.10	105.66
S27	El fous	1.64	2.45	21.26	60.97	86.33	105.95
S28	Kakara	2.64	2.52	29.26	60.97	95.40	117.08
S29	Kakara	2.54	2.90	28.35	61.28	95.07	116.68
S30	Kakara	1.79	2.59	26.29	64.90	95.57	117.29
S31	Kelara	1.53	2.40	19.89	65.20	89.03	109.26
S32	Kelara	1.22	1.97	16.23	73.65	93.08	114.23
S33	Kelara	1.62	2.36	23.09	66.11	93.18	114.35

S34	Tondiya	2.03	3.81	33.61	53.13	92.58	113.61
S35	Tondiya	1.31	2.14	18.98	63.39	85.82	105.33
S36	Tondiya	1.17	2.00	17.61	63.69	84.47	103.66
S37	Gelogical camp	0.55	1.62	10.98	24.15	37.30	45.77
S38	Uro east	0.85	12.02	76.37	33.20	122.43	150.26
S39	Uro west	5.87	29.72	374.06	ND	409.64	502.73
S40	Uro market	0.67	11.33	79.34	27.17	118.50	145.43
S41	Uro middle	0.42	4.43	30.41	16.00	51.26	62.90
S42	Dar el-salam school	0.55	5.33	35.44	17.81	59.12	72.56
S43	Um takatik	0.51	3.40	21.26	16.60	41.78	51.27
S44	Um takatik	0.68	1.97	14.18	13.28	30.11	36.95
S45	Um takatik	0.14	0.95	7.77	9.06	17.92	21.99
S46	Um takatik(Termite)	0.60	2.26	16.69	13.89	33.43	41.03
S47	Kurun	1.03	7.33	56.93	ND	65.29	80.12
S48	Kurun hill	0.63	2.86	23.55	16.90	43.94	53.93
S49	Kurun	0.63	9.40	68.14	16.90	95.07	116.67
S50	Kurun	0.45	1.47	10.29	17.21	29.42	36.11
S51	Abu galaha	0.40	1.50	9.83	18.71	30.45	37.37
S52	Tumluk hill	0.53	3.97	29.04	31.39	64.94	79.69
S53	Tumluk hill	0.63	4.04	29.26	30.49	64.43	79.07
S54	Tumluk	0.49	3.43	28.12	26.87	58.90	72.28
S55	Aryab camp	0.45	1.64	11.89	20.22	34.20	41.97
S56	Aryab (trench)	0.28	0.79	6.63	32.30	39.99	49.08
S57	Aryab	0.38	2.69	19.21	28.37	50.65	62.16
S58	Uro hill height	0.80	9.92	69.50	48.00	128.22	157.35
S59	Near Uro village	0.64	9.47	68.14	42.56	120.81	148.26
S60	Near Uro hill	0.55	7.88	52.59	21.43	82.45	101.18
S61	Uro village	0.94	10.11	72.02	ND	83.07	101.95
S62	Uro village	0.73	0.48	10.29	ND	11.49	14.10
S63	Tirmi stream	0.54	3.88	32.01	19.62	56.05	68.78
S64	Stream between Tirmi and Uro	0.42	3.59	27.90	43.47	75.38	92.51
S65	Western north of Uro	0.60	5.38	40.47	19.32	65.76	80.71
S66	El layoon farm	0.73	11.06	91.46	32.00	135.24	165.97
S67	El layoon village	0.42	0.69	6.17	22.34	29.62	36.35
S68	El layoon	0.32	0.64	5.69	19.92	26.57	32.61
S69	El layoon	0.75	7.76	50.99	ND	59.49	73.01

Mean	1.88	4.56	40.06	42.31	88.81	108.99
SD	1.87	4.19	46.52	24.37	55.03	67.54
Min	0.14	0.48	5.69	9.06	11.49	14.10
Max	7.79	29.72	374.06	86.63	409.64	502.73

Table (8): 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

Sample code	Location	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs.Dose Rate	Ann. Eff. Dose
S1	Katla	234.27	74.68	101.31	87.59	497.86	610.99
S2	Katla	199.19	67.34	90.02	88.85	445.41	546.62
S3	Katla	131.28	46.83	61.80	74.04	313.95	385.30
S4	Walaey	183.12	92.91	96.85	70.26	443.15	543.85
S5	Walaey	114.54	46.83	57.04	68.05	286.47	351.56
S6	Walaey	245.59	79.75	108.14	90.43	523.91	642.96
S7	Kogoriea	150.07	74.68	79.03	66.80	370.58	454.79
S8	Kogoriea	176.33	66.08	84.97	71.21	398.58	489.15
S9	Kogoriea	135.81	46.33	62.98	41.28	286.40	351.48
S10	El karko	152.11	52.66	68.63	74.04	347.44	426.40
S11	El karko	161.39	55.69	68.63	70.58	356.29	437.25
S12	El karko	118.15	48.10	56.15	69.95	292.35	358.79
S13	El funda	43.46	21.77	24.07	68.69	157.98	193.88
S14	El funda	41.88	21.52	23.17	69.95	156.52	192.08
S15	El funda	64.51	29.36	32.09	69.63	195.60	240.04
S16	El netil	46.40	25.08	24.36	67.11	162.95	199.98
S17	El netil	37.35	17.72	21.09	65.85	142.01	174.29
S18	El netil	48.21	23.04	25.85	57.03	154.12	189.15
S19	Sallara	66.10	27.60	33.87	62.70	190.26	233.50
S20	Sallara	71.75	35.19	41.30	57.03	205.27	251.91
S21	Sallara	86.02	29.62	39.51	64.59	219.74	269.67
S22	Hajer el sultan	57.95	27.60	30.01	53.25	168.80	207.16
S23	Hajer el sultan	50.25	29.87	30.90	30.56	141.58	173.75
S24	Hajer el sultan	50.02	27.09	30.01	27.10	134.21	164.71
S25	El fous	60.21	31.90	30.60	51.99	174.70	214.40

S26	El fous	46.62	32.15	32.68	58.92	170.37	209.09
S27	El fous	51.61	26.08	27.63	63.65	168.96	207.35
S28	Kakara	83.30	26.83	38.03	63.65	211.80	259.93
S29	Kakara	80.13	30.88	36.84	63.96	211.81	259.94
S30	Kakara	56.36	27.60	34.16	67.74	185.86	228.10
S31	Kelara	48.21	25.57	25.85	68.06	167.68	205.79
S32	Kelara	38.48	21.01	21.09	76.88	157.47	193.25
S33	Kelara	51.15	25.06	30.01	69.00	175.23	215.04
S34	Tondiya	64.06	40.50	43.67	55.45	203.69	249.98
S35	Tondiya	41.42	22.79	24.66	66.17	155.04	190.27
S36	Tondiya	36.85	21.27	22.88	66.48	147.48	180.99
S37	Gelogical camp	17.43	17.21	14.26	25.21	74.11	90.96
S38	Uro east	26.71	127.84	99.23	34.66	288.45	353.99
S39	Uro west	184.93	316.19	486.06	ND	987.19	1211.51
S40	Uro market	21.05	120.50	103.10	28.36	273.00	335.04
S41	Uro middle	13.35	47.09	39.51	16.70	116.66	143.16
S42	Dar el-salam school	17.20	56.71	46.05	18.59	138.55	170.03
S43	Um takatik	16.07	36.20	27.63	17.33	97.24	119.33
S44	Um takatik	21.28	21.01	18.42	13.86	74.57	91.52
S45	Um takatik	4.30	10.13	10.10	9.45	33.98	41.70
S46	Um takatik(Termite)	18.80	24.05	21.69	14.49	79.03	96.99
S47	Kurun	32.37	77.97	73.98	ND	184.32	226.21
S48	Kurun hill	19.92	30.38	30.60	17.64	98.55	120.94
S49	Kurun	19.92	10ND	88.54	17.64	226.10	277.48
S50	Kurun	14.27	15.69	13.37	17.96	61.29	75.22
S51	Abu galaha	12.68	15.95	12.77	19.53	60.94	74.78
S52	Tumluk hill	16.75	42.28	37.73	32.77	129.53	158.96
S53	Tumluk hill	19.92	43.04	38.03	31.82	132.81	162.98
S54	Tumluk	15.39	36.46	36.54	28.04	116.43	142.88

S55	Aryab camp	14.03	17.47	15.45	21.11	68.06	83.52
S56	Aryab (trench)	8.83	8.35	8.62	33.71	59.51	73.04
S57	Aryab	12.00	28.61	24.96	29.62	95.18	116.81
S58	Uro hill height	25.12	105.56	90.32	50.10	271.10	332.70
S59	Near Uro village	20.14	100.76	88.54	44.43	253.86	311.55
S60	Near Uro hill	17.43	83.79	68.33	22.37	191.93	235.54
S61	Uro village	29.65	107.59	93.59	ND	230.83	283.28
S62	Uro village	22.86	5.06	13.37	ND	41.30	50.68
S63	Tirmi stream	16.98	41.27	41.59	20.48	120.32	147.66
S64	Stream between Tirmi and Uro	13.35	38.23	36.25	45.37	133.20	163.47
S65	Western north of Uro	18.78	57.21	52.59	20.16	148.75	182.56
S66	El layoon farm	22.86	117.72	118.84	33.40	292.82	359.36
S67	El layoon village	13.35	7.34	8.02	23.32	52.03	63.86
S68	El layoon	9.96	6.83	7.40	20.79	44.98	55.21
S69	El layoon	23.54	82.53	66.26	ND	172.32	211.48
Mean		59.21	48.49	52.05	44.17	203.92	250.26
SD		58.83	44.61	60.45	25.44	145.48	178.54
Min		4.30	5.06	7.40	9.45	33.98	41.70
Max		245.59	316.19	486.06	90.43	987.19	1211.51

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 SAITO DRCFs and annual effective dose (µSv/y) in rock samples

Sample Code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
R70	Katla	17.94	22.41	ND	40.35	49.52
R71	Walaey	115.79	62.02	56.71	234.53	287.82
R72	Kogoriea	8.63	11.54	3.78	23.96	29.40
R73	El karko	25.76	92.13	ND	117.88	144.67
R74	EL funda	54.37	81.03	71.84	207.24	254.33
R75	El netil	35.92	55.68	70.89	162.50	199.42
R76	Sallara	47.33	72.66	77.82	197.81	242.77
R77	Hajer el-sultan	42.17	60.21	67.74	170.12	208.78
R78	El fous	51.16	67.23	66.80	185.19	227.27
R79	Kakara	103.62	138.07	66.17	307.87	377.83
R80	Kelara	36.72	61.34	76.25	174.31	213.92
R81	Tondiya	45.84	98.46	78.45	222.76	273.38
R82	Um takatik hill	317.37	149.17	58.92	525.45	644.85
R83	Kurun hill	144.57	103.90	ND	248.47	304.93
R84	Kurun hill	302.38	132.19	ND	434.57	533.32
R85	Beside kurun hill	422.76	197.38	77.82	697.96	856.57
R86	Beside kurun hill	366.72	156.41	67.11	590.24	724.37
R87	Tumluk	55.16	17.66	ND	72.82	89.37
R88	Aryab	23.78	23.31	18.27	65.37	80.23
R89	Uro hill	255.51	119.97	45.69	421.16	516.87
R90	Tirmi hill	43.14	6.56	21.74	71.45	87.68
R91	Uro market hill	363.54	168.18	66.17	597.89	733.75
Mean		130.92	86.25	45.10	262.27	321.87
SD		136.57	54.53	31.94	197.13	241.93
Min		8.63	6.56	3.78	23.96	29.40
Max		422.76	197.38	78.45	697.96	856.57

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

Sample Code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
R70	Katla	14.76	19.17	ND	33.93	41.64
R71	Walaey	95.26	53.06	51.41	199.74	245.13
R72	Kogoriea	7.10	9.88	3.43	20.40	25.04
R73	El karko	21.19	78.82	ND	100.01	122.74
R74	EL funda	44.73	69.33	65.12	179.18	219.90
R75	El netil	29.55	47.64	64.26	141.46	173.60
R76	Sallara	38.94	62.17	70.55	171.65	210.66
R77	Hajer el-sultan	34.69	51.52	61.41	147.62	181.16
R78	El fous	42.09	57.52	60.55	160.16	196.56
R79	Kakara	85.25	118.14	59.98	263.37	323.22
R80	Kelara	30.21	52.48	69.12	151.81	186.30
R81	Tondiya	37.72	84.24	71.12	193.08	236.95
R82	Um takatik hill	261.10	127.63	53.41	442.14	542.61
R83	Kurun hill	118.94	88.89	ND	207.84	255.06
R84	Kurun hill	248.77	113.10	ND	361.87	444.11
R85	Beside kurun hill	347.81	168.88	70.55	587.24	720.68
R86	Beside kurun hill	301.71	133.82	60.83	496.37	609.16
R87	Tumluk	45.38	15.11	ND	60.49	74.24
R88	Aryab	19.57	19.95	16.57	56.08	68.83
R89	Uro hill	210.21	102.64	41.41	354.27	434.77
R90	Tirmi hill	35.49	5.62	19.71	60.82	74.64
R91	Uro market hill	299.09	143.89	59.98	502.96	617.26
Mean		107.71	73.80	40.88	222.39	272.92
SD		112.36	46.65	28.96	165.04	202.54
Min		7.10	5.62	3.43	20.40	25.04
Max		347.81	168.88	71.12	587.24	720.68

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 GEANT DRCFs and annual effective dose (µSv/y) in rock samples

Sample Code	Location	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
R70	Katla	15.50	20.17	ND	35.67	43.77
R71	Walaey	100.03	55.83	54.33	210.19	257.96
R72	Kogoriea	7.46	10.39	3.62	21.47	26.35
R73	El karko	22.25	82.93	ND	105.18	129.08
R74	EL funda	46.97	72.95	68.82	188.74	231.63
R75	El netil	31.03	50.13	67.92	149.07	182.95
R76	Sallara	40.89	65.41	74.56	180.85	221.95
R77	Hajer el-sultan	36.43	54.20	64.90	155.53	190.87
R78	El fous	44.20	60.52	63.99	168.71	207.05
R79	Kakara	89.52	124.30	63.39	277.20	340.19
R80	Kelara	31.72	55.22	73.05	159.99	196.34
R81	Tondiya	39.60	88.64	75.16	203.40	249.62
R82	Um takatik hill	274.15	134.28	56.45	464.88	570.52
R83	Kurun hill	124.89	93.53	ND	218.42	268.05
R84	Kurun hill	261.21	119.00	ND	380.21	466.60
R85	Beside kurun hill	365.20	177.68	74.56	617.44	757.75
R86	Beside kurun hill	316.79	140.80	64.30	521.89	640.48
R87	Tumluk	47.65	15.89	ND	63.55	77.99
R88	Aryab	20.55	20.99	17.51	59.04	72.46
R89	Uro hill	220.72	108.00	43.77	372.48	457.13
R90	Tirmi hill	37.27	5.91	20.83	64.00	78.55
R91	Uro market hill	314.04	151.40	63.39	528.83	649.00
Mean		113.09	77.64	43.21	233.94	287.10
SD		117.97	49.09	30.60	173.47	212.89
Min		7.46	5.91	3.62	21.47	26.35
Max		365.20	177.68	75.16	617.44	757.75

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 rock samples

Sample Code	**Location**	**^{238}U**	**^{232}Th**	**^{40}K**	**Abs. Dose Rate**	**Ann. Eff. Dose**
R70	Katla	17.90	22.41	ND	40.31	49.47
R71	Walaey	115.54	62.02	56.71	234.28	287.51
R72	Kogoriea	8.61	11.54	3.78	23.94	29.38
R73	El karko	25.70	92.13	ND	117.82	144.60
R74	EL funda	54.25	81.03	71.84	207.12	254.19
R75	El netil	35.84	55.68	70.89	162.42	199.33
R76	Sallara	47.23	72.66	77.82	197.71	242.64
R77	Hajer el-sultan	42.08	60.21	67.74	170.03	208.67
R78	El fous	51.05	67.23	66.80	185.08	227.13
R79	Kakara	103.40	138.07	66.17	307.64	377.55
R80	Kelara	36.64	61.34	76.25	174.23	213.82
R81	Tondiya	45.74	98.46	78.45	222.66	273.26
R82	Um takatik hill	316.68	149.17	58.92	524.77	644.01
R83	Kurun hill	144.26	103.90	ND	248.16	304.55
R84	Kurun hill	301.72	132.19	ND	433.91	532.52
R85	Beside kurun hill	421.85	197.38	77.82	697.05	855.45
R86	Beside kurun hill	365.93	156.41	67.11	589.45	723.40
R87	Tumluk	55.04	17.66	ND	72.70	89.22
R88	Aryab	23.73	23.31	18.27	65.32	80.17
R89	Uro hill	254.96	119.97	45.69	420.61	516.19
R90	Tirmi hill	43.05	6.56	21.74	71.35	87.57
R91	Uro market hill	362.76	168.18	66.17	597.10	732.79
Mean		130.63	86.25	45.10	261.98	321.52
SD		136.27	54.53	31.94	196.85	241.58
Min		8.61	6.56	3.78	23.94	29.38
Max		421.85	197.38	78.45	697.05	855.45

Table (13): 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 SAITO DRCFs and annual effective dose (µSv/y) in rock samples

Sample Code	**Locations**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**Abs. Dose. Rate**	**Ann. Eff. Dose**
R70	Katla	1.03	2.12	15.47	ND	18.62	22.85
R71	Walaey	2.84	14.81	91.80	56.71	166.17	203.93
R72	Kogoriea	0.53	1.02	7.48	3.78	12.81	15.72
R73	El karko	4.23	0.78	44.61	ND	49.62	60.89
R74	EL funda	3.72	6.43	46.93	71.84	128.92	158.22
R75	El netil	2.55	4.19	31.46	70.89	109.10	133.89
R76	Sallara	3.33	5.48	41.78	77.82	128.41	157.59
R77	Hajer el-sultan	2.76	5.21	34.81	67.74	110.52	135.64
R78	El fous	3.08	6.13	43.58	66.80	119.59	146.77
R79	Kakara	6.33	12.33	88.97	66.17	173.79	213.28
R80	Kelara	2.81	3.92	34.81	76.25	117.80	144.56
R81	Tondiya	4.52	4.67	45.13	78.45	132.77	162.94
R82	Um takatik hill	6.84	38.48	267.16	58.92	371.39	455.79
R83	Kurun hill	4.76	13.73	149.57	ND	168.07	206.26
R84	Kurun hill	6.06	37.40	249.11	ND	292.57	359.05
R85	Beside kurun hill	9.05	51.43	354.58	77.82	492.89	604.89
R86	Beside kurun hill	7.17	44.64	307.39	67.11	426.31	523.18
R87	Tumluk	0.81	6.97	44.35	ND	52.14	63.98
R88	Aryab	1.07	3.08	18.57	18.27	40.99	50.31
R89	Uro hill	5.50	31.30	212.75	45.69	295.23	362.32
R90	Tirmi hill	0.30	5.50	34.30	21.74	61.84	75.90
R91	Uro market hill	7.71	45.12	298.36	66.17	417.36	512.20
Mean		3.96	15.67	111.95	45.10	176.68	216.83
SD		2.50	16.87	112.96	31.94	141.95	174.20
Min		0.30	0.78	7.48	3.78	12.81	15.72
Max		9.05	51.43	354.58	78.45	492.89	604.89

Table (14): 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 rock samples

Sample Code	Locations	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose. Rate	Ann. Eff. Dose
R70	Katla	0.67	1.61	13.06	ND	15.34	18.83
R71	Walaey	1.84	11.26	77.49	51.41	142.00	174.27
R72	Kogoriea	0.34	0.77	6.31	3.43	10.86	13.32
R73	El karko	2.74	0.59	37.66	ND	40.99	50.30
R74	EL funda	2.41	4.89	39.62	65.12	112.03	137.49
R75	El netil	1.66	3.18	26.56	64.26	95.66	117.40
R76	Sallara	2.16	4.16	35.26	70.55	112.13	137.61
R77	Hajer el-sultan	1.79	3.96	29.39	61.41	96.54	118.48
R78	El fous	2.00	4.66	36.79	60.55	104.00	127.63
R79	Kakara	4.11	9.37	75.10	59.98	148.55	182.31
R80	Kelara	1.82	2.98	29.39	69.12	103.31	126.78
R81	Tondiya	2.93	3.55	38.09	71.12	115.69	141.97
R82	Um takatik hill	4.44	29.24	225.51	53.41	312.60	383.64
R83	Kurun hill	3.09	10.44	126.25	ND	139.78	171.54
R84	Kurun hill	3.93	28.43	210.28	ND	242.63	297.77
R85	Beside kurun hill	5.87	39.09	299.31	70.55	414.81	509.07
R86	Beside kurun hill	4.65	33.93	259.47	60.83	358.88	440.44
R87	Tumluk	0.52	5.30	37.44	ND	43.26	53.09
R88	Aryab	0.69	2.34	15.67	16.57	35.27	43.29
R89	Uro hill	3.57	23.79	179.58	41.41	248.35	304.78
R90	Tirmi hill	0.20	4.18	28.95	19.71	53.04	65.09
R91	Uro market hill	5.00	34.29	251.85	59.98	351.12	430.91
Mean		2.56	11.91	94.50	40.88	149.86	183.91
SD		1.62	12.82	95.35	28.96	118.84	145.84
Min		0.20	0.59	6.31	3.43	10.86	13.32
Max		5.87	39.09	299.31	71.12	414.81	509.07

Table (15): 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 GEANT DRCFs and annual effective dose (μSv/y) in rock samples

Sample Code	Locations	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose. Rate	Ann. Eff. Dose
R70	Katla	0.71	1.69	13.72	ND	16.12	19.78
R71	Walaey	1.97	11.78	81.40	54.33	149.48	183.44
R72	Kogoriea	0.37	0.81	6.63	3.62	11.43	14.03
R73	El karko	2.92	0.62	39.55	ND	43.10	52.89
R74	EL funda	2.57	5.12	41.61	68.82	118.12	144.96
R75	El netil	1.77	3.33	27.90	67.92	100.91	123.84
R76	Sallara	2.31	4.35	37.04	74.56	118.26	145.13
R77	Hajer el-sultan	1.91	4.14	30.87	64.90	101.82	124.96
R78	El fous	2.13	4.88	38.64	63.99	109.64	134.56
R79	Kakara	4.38	9.80	78.88	63.39	156.45	192.01
R80	Kelara	1.95	3.12	30.87	73.05	108.98	133.75
R81	Tondiya	3.13	3.71	40.01	75.16	122.01	149.74
R82	Um takatik hill	4.73	30.60	236.87	56.45	328.65	403.33
R83	Kurun hill	3.30	10.92	132.61	ND	146.83	180.20
R84	Kurun hill	4.20	29.74	220.87	ND	254.80	312.71
R85	Beside kurun hill	6.26	40.90	314.38	74.56	436.10	535.20
R86	Beside kurun hill	4.96	35.50	272.54	64.30	377.30	463.03
R87	Tumluk	0.56	5.54	39.33	ND	45.43	55.75
R88	Aryab	0.74	2.45	16.46	17.51	37.16	45.60
R89	Uro hill	3.81	24.89	188.63	43.77	261.09	320.42
R90	Tirmi hill	0.21	4.38	30.41	20.83	55.82	68.51
R91	Uro market hill	5.34	35.88	264.54	63.39	369.15	453.03
Mean		2.74	12.46	99.26	43.21	157.67	193.49
SD		1.73	13.41	100.16	30.60	124.88	153.26
Min		0.21	0.62	6.63	3.62	11.43	14.03
Max		6.26	40.90	314.38	75.16	436.10	535.20

Table (16): 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 rock samples

Sample Code	**Locations**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**Abs. Dose. Rate**	**Ann. Eff. Dose**
R70	Katla	22.41	17.98	17.82	ND	58.21	71.44
R71	Walaey	62.02	125.31	105.77	56.71	349.82	429.31
R72	Kogoriea	11.54	8.61	8.62	3.78	32.55	39.94
R73	El karko	92.13	6.59	51.40	ND	150.12	184.23
R74	EL funda	81.03	54.43	54.07	71.84	261.37	320.77
R75	El netil	55.68	35.44	36.25	70.89	198.26	243.32
R76	Sallara	72.66	46.33	48.13	77.82	244.94	300.60
R77	Hajer el-sultan	60.21	44.05	40.11	67.74	212.12	260.32
R78	El fous	67.23	51.90	50.21	66.80	236.13	289.79
R79	Kakara	138.07	104.30	102.50	66.17	411.04	504.45
R80	Kelara	61.34	33.16	40.11	76.25	210.86	258.78
R81	Tondiya	98.46	39.49	51.99	78.45	268.40	329.40
R82	Um takatik hill	149.16	325.56	307.80	58.92	841.44	1032.65
R83	Kurun hill	103.89	116.20	172.32	ND	392.41	481.58
R84	Kurun hill	132.19	316.45	287.00	ND	735.64	902.81
R85	Beside kurun hill	197.38	435.18	408.52	77.82	1118.90	1373.16
R86	Beside kurun hill	156.41	377.71	354.15	67.11	955.38	1172.48
R87	Tumluk	17.65	58.98	51.10	ND	127.74	156.77
R88	Aryab	23.31	26.08	21.39	18.27	89.05	109.28
R89	Uro hill	119.97	264.80	245.11	45.69	675.57	829.08
R90	Tirmi hill	6.57	46.58	39.51	21.74	114.40	140.40
R91	Uro market hill	168.18	381.76	343.75	66.17	959.85	1177.97
Mean		86.25	132.59	128.98	45.10	392.92	482.21
SD		54.53	142.73	130.15	31.94	330.20	405.23
Min		6.57	6.59	8.62	3.78	32.55	39.94
Max		197.38	435.18	408.52	78.45	1118.90	1373.16

Table (17): 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 SAITO DRCFs and annual effective dose (µSv/y) in crops samples

Sample Code	Location	Type	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	2.57	7.17	14.18	23.92	29.36
C 94	Walaey	Mango	4.71	7.69	18.90	31.31	38.42
C 95	Walaey	Tomato	9.35	12.45	58.29	80.09	98.28
C 97	Kogoriea	Sorghum	4.10	6.79	12.60	23.49	28.83
C 99	El karko	Sorghum	2.72	7.07	14.77	24.56	30.15
C 103	Hajer el sultan	Sorghum	2.02	0.28	9.45	11.75	14.43
C 105	El layoon	Chili	13.79	11.32	53.56	78.67	96.55
C 109	Kabous	Dry Tomato	1.96	5.94	47.66	55.56	68.19
C 110	El abbasiya	Tomato	15.94	24.90	69.32	110.15	135.18
C 111	El biteira	Okra	1.52	4.53	28.54	34.60	42.46
C 113	El biteira	Tomato	6.00	8.49	70.10	84.59	103.81
Mean			5.88	8.78	36.13	50.79	62.33
SD			5.00	6.23	23.96	32.63	40.04
Min			1.52	0.28	9.45	11.75	14.43
Max			15.94	24.90	70.10	110.15	135.18

Table (18): 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 crops samples

Sample Code	Location	Type	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	2.12	6.13	12.85	21.10	25.90
C 94	Walaey	Mango	3.87	6.58	17.14	27.59	33.86
C 95	Walaey	Tomato	7.69	10.65	52.84	71.18	87.35
C 97	Kogoriea	Sorghum	3.37	5.81	11.42	20.60	25.29
C 99	El karko	Sorghum	2.24	6.05	13.39	21.68	26.61
C 103	Hajer el sultan	Sorghum	1.66	0.24	8.57	10.47	12.85
C 105	El layoon	Chili	11.34	9.68	48.55	69.58	85.39
C 109	Kabous	Dry Tomato	1.62	5.09	43.20	49.90	61.24
C 110	El abbasiya	Tomato	13.11	21.30	62.83	97.25	119.35
C 111	El biteira	Okra	1.25	3.88	25.87	31.00	38.05
C 113	El biteira	Tomato	4.93	7.26	63.55	75.74	92.95
Mean			4.84	7.52	32.75	45.10	55.35
SD			4.12	5.33	21.72	28.96	35.55
Min			1.25	0.24	8.57	10.47	12.85
Max			13.11	21.30	63.55	97.25	119.35

Table (19): 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 crops samples

Sample Code	Location	Type	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	2.22	6.45	13.58	22.26	27.32
C 94	Walaey	Mango	4.07	6.93	18.11	29.11	35.72
C 95	Walaey	Tomato	8.08	11.21	55.84	75.12	92.20
C 97	Kogoriea	Sorghum	3.54	6.11	12.07	21.73	26.66
C 99	El karko	Sorghum	2.35	6.37	14.15	22.87	28.06
C 103	Hajer el sultan	Sorghum	1.74	0.26	9.06	11.05	13.57
C 105	El layoon	Chili	11.91	10.19	51.32	73.42	90.10
C 109	Kabous	Dry Tomato	1.70	5.35	45.66	52.70	64.68
C 110	El abbasiya	Tomato	13.77	22.41	66.41	102.59	125.90
C 111	El biteira	Okra	1.32	4.08	27.34	32.74	40.18
C 113	El biteira	Tomato	5.18	7.64	67.16	79.98	98.16
Mean			5.08	7.91	34.61	47.60	58.41
SD			4.32	5.61	22.96	30.57	37.51
Min			1.32	0.26	9.06	11.05	13.57
Max			13.77	22.41	67.16	102.59	125.90

Table (20): 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 crops samples

Sample Code	Location	Type	^{238}U	^{232}Th	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	2.57	7.17	14.18	23.92	29.35
C 94	Walaey	Mango	4.70	7.69	18.90	31.30	38.41
C 95	Walaey	Tomato	9.33	12.45	58.29	80.07	98.26
C 97	Kogoriea	Sorghum	4.09	6.79	12.60	23.48	28.82
C 99	El karko	Sorghum	2.72	7.07	14.77	24.56	30.14
C 103	Hajer el sultan	Sorghum	2.01	0.28	9.45	11.75	14.42
C 105	El layoon	Chili	13.76	11.32	53.56	78.64	96.51
C 109	Kabous	Dry Tomato	1.96	5.94	47.66	55.56	68.18
C 110	El abbasiya	Tomato	15.90	24.90	69.32	110.12	135.14
C 111	El biteira	Okra	1.52	4.53	28.54	34.59	42.45
C 113	El biteira	Tomato	5.98	8.49	70.10	84.57	103.79
Mean			5.87	8.78	36.13	50.78	62.32
SD			4.99	6.23	23.96	32.62	40.03
Min			1.52	0.28	9.45	11.75	14.42
Max			15.90	24.90	70.10	110.12	135.14

Table (21): 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 SAITO DRCFs and annual effective dose (µSv/y) in crops samples

Sample Code	Location	Type	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	0.33	0.55	0.43	14.18	15.49	19.00
C 94	Walaey	Mango	0.35	0.48	4.64	18.90	24.38	29.92
C 95	Walaey	Tomato	0.57	0.45	12.89	58.29	72.20	88.61
C 97	Kogoriea	Sorghum	0.31	0.50	3.44	12.60	16.85	20.68
C 99	El karko	Sorghum	0.32	0.09	4.03	14.77	19.22	23.58
C 103	Hajer el sultan	Sorghum	0.01	0.04	3.22	9.45	12.73	15.62
C 105	El layoon	Chili	0.52	1.50	12.89	53.56	68.47	84.03
C 109	Kabous	Dry Tomato	0.27	0.11	2.58	47.66	50.62	62.12
C 110	El abbasiya	Tomato	1.14	0.60	23.21	69.32	94.27	115.69
C 111	El biteira	Okra	0.21	0.07	2.13	28.54	30.95	37.98
C 113	El biteira	Tomato	0.39	0.45	7.09	70.10	78.03	95.76
Mean			0.40	0.44	6.96	36.13	43.93	53.91
SD			0.29	0.41	6.78	23.96	29.70	36.45
Min			0.01	0.04	0.43	9.45	12.73	15.62
Max			1.14	1.50	23.21	70.10	94.27	115.69

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 crops samples

Sample Code	Location	Type	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	0.21	0.42	0.36	12.85	13.84	16.99
C 94	Walaey	Mango	0.23	0.36	3.92	17.14	21.65	26.57
C 95	Walaey	Tomato	0.37	0.34	10.88	52.84	64.43	79.07
C 97	Kogoriea	Sorghum	0.20	0.38	2.90	11.42	14.91	18.29
C 99	El karko	Sorghum	0.21	0.07	3.40	13.39	17.07	20.95
C 103	Hajer el sultan	Sorghum	0.01	0.03	2.72	8.57	11.33	13.90
C 105	El layoon	Chili	0.34	1.14	10.88	48.55	60.91	74.75
C 109	Kabous	Dry Tomato	0.18	0.09	2.18	43.20	45.64	56.01
C 110	El abbasiya	Tomato	0.74	0.45	19.59	62.83	83.62	102.62
C 111	El biteira	Okra	0.13	0.05	1.79	25.87	27.86	34.19
C 113	El biteira	Tomato	0.25	0.34	5.98	63.55	70.13	86.06
Mean			0.26	0.33	5.87	32.75	39.22	48.13
SD			0.19	0.31	5.73	21.72	26.49	32.51
Min			0.01	0.03	0.36	8.57	11.33	13.90
Max			0.74	1.14	19.59	63.55	83.62	102.62

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 GEANT DRCFs and annual effective dose (μSv/y) in crops samples

Sample Code	Location	Type	^{212}Pb	^{214}Pb	^{214}Bi	^{40}K	Abs. Dose Rate	Ann. Eff. Dose
C 92	Katla	Sorghum	0.23	0.44	0.38	13.58	14.63	17.95
C 94	Walaey	Mango	0.24	0.38	4.12	18.11	22.85	28.05
C 95	Walaey	Tomato	0.40	0.36	11.43	55.84	68.03	83.48
C 97	Kogoriea	Sorghum	0.22	0.40	3.05	12.07	15.73	19.31
C 99	El karko	Sorghum	0.22	0.07	3.57	14.15	18.02	22.12
C 103	Hajer el sultan	Sorghum	0.01	0.03	2.86	9.06	11.95	14.67
C 105	El layoon	Chili	0.36	1.19	11.43	51.32	64.29	78.91
C 109	Kabous	Dry Tomato	0.19	0.09	2.29	45.66	48.22	59.18
C 110	El abbasiya	Tomato	0.79	0.48	20.58	66.41	88.25	108.31
C 111	El biteira	Okra	0.14	0.06	1.88	27.34	29.43	36.12
C 113	El biteira	Tomato	0.27	0.36	6.29	67.16	74.07	90.91
Mean			0.28	0.35	6.17	34.61	41.41	50.82
SD			0.20	0.33	6.01	22.96	27.96	34.32
Min			0.01	0.03	0.38	9.06	11.95	14.67
Max			0.79	1.19	20.58	67.16	88.25	108.31

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 crops samples

Sample Code	**Location**	**Type**	**^{212}Pb**	**^{214}Pb**	**^{214}Bi**	**^{40}K**	**Abs. Dose Rate**	**Ann. Eff. Dose**
C 92	Katla	Sorghum	7.17	4.64	0.49	14.18	26.49	32.50
C 94	Walaey	Mango	7.69	4.05	5.35	18.90	36.00	44.18
C 95	Walaey	Tomato	12.45	3.80	14.85	58.29	89.39	109.70
C 97	Kogoriea	Sorghum	6.79	4.22	3.96	12.60	27.57	33.83
C 99	El karko	Sorghum	7.07	0.79	4.64	14.77	27.28	33.47
C 103	Hajer el sultan	Sorghum	0.28	0.31	3.71	9.45	13.76	16.89
C 105	El layoon	Chili	11.32	12.66	14.85	53.56	92.39	113.39
C 109	Kabous	Dry Tomato	5.94	0.95	2.97	47.66	57.52	70.59
C 110	El abbasiya	Tomato	24.90	5.06	26.74	69.32	126.02	154.65
C 111	El biteira	Okra	4.53	0.60	2.45	28.54	36.12	44.32
C 113	El biteira	Tomato	8.49	3.80	8.17	70.10	90.56	111.13
Mean			8.78	3.72	8.02	36.13	56.64	69.52
SD			6.23	3.47	7.81	23.96	36.90	45.29
Min			0.28	0.31	0.49	9.45	13.76	16.89
Max			24.90	12.66	26.74	70.10	126.02	154.65