

# CHAPTER ONE

## INTRODUCTION

### 1.1 Introduction

Measurement of natural radioactivity in sediment, soil, waters and any other samples is very important to determine the amount of change in natural background with time as a result of any radioactive decay. Monitoring of any release of radioactivity to the environment is helpful for environmental protection and the important radiological concentration consequence of natural radioactivity is the effects of  $\gamma$ - ray on the human body because stochastic effect caused by few  $\mu\text{Sv}$  or less.

The River Nile drains materials of different source rocks (igneous, metamorphic and sedimentary) along its course from the central and eastern parts of Africa in the south to the Mediterranean Sea in the north (about 6285 km). The geology and origin of the study area, as a part of the River Nile, has been treated by many authors. Indeed, enrichment or deficiency of certain elements within rocks, soils or water may be responsible for certain diseases in plants, animals and humans. Several types of pollution were found in the alluvial environment as organic materials as well as major and trace metals. Pollution may be derived from dust fall, erosion, chemical eathering or from decay of dead aquatic organisms. The pollution also may be derived from human activity as industrial and agricultural activities or from sewage and ship's wastes [1].

During evolution of the earth, many of the primordial radionuclides decayed below detectable levels so that the residual radioactivity can be divided into:

- The primary radioactivity, due to radionuclides with half-lives comparable to or greater than the estimated age of the earth ( $4.6 \times 10^9$  year) e.g.  $^{238}\text{U}$ ,  $^{235}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ .
- The secondary radioactivity, resulting from radioactivity decay of the primary radionuclides, i.e. the daughters of the primary radionuclides. Beside these, there are some short-lived transuranic radionuclides ( $^{239}\text{Pu}$  and  $^{237}\text{Np}$ ) which are induced through the capture of neutrons by uranium isotopes [2].

## **1.2 Research Problem**

Determine of activity concentration and its environmental pollution effects in northern Sudan by select different area from river Nile banks in north Sudan and collect different sediments and water samples with known location and depth then analyzing the samples by using  $\gamma$  -ray spectroscopy.

## **1.3 Aim of the Work**

The present study aims to establish a radiological baseline data by study the radioactivity concentrations of the natural and man-made radionuclides of the River Nile environment. This study select different areas from river Nile banks in north Sudan to collect different sediments and water samples from it with known location and depth and analyzing the samples using  $\gamma$  -ray spectroscopy, this is mainly to.

- To study the environmental behavior of the radionuclides in the aquatic ecosystem for its great importance in prediction the radiological impacts on man and his environment.
- To adjust the system for identification of real changes in the radioactivity levels in the River Nile environment and to correlate this data with the occurrence of any accidental radioactive releases.

- To assess the environmental pollution effects on man caused by radionuclide in the selected area from Nile banks in north Sudan.
- To insure compliance with the world permissible standards for radioactivity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in soil.
- To provide continuing reassurance of adequate radioactive control of effluents of the River Nile as it is the main source of water in Sudan.
- To assess the associated hazard caused by radioactivity of radionuclide.
- To determine the potential risk by calculation of radiation doses (due to the daily Exposures from River Nile environment to man) from the theoretical modeling.
- To study the changes in sediments precipitations of radioactive isotopes.

#### **1.4 Environmental Radioactivity Stander Levels**

The world average radioactivity concentration (range) of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in sediments and soil were 25(10-50), 25(7-50) and 370(100-700) Bq/kg respectively. The average absorbed dose rate in air one meter above the ground due to  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  isotopes were 11, 17 and 16 nGy/hr respectively, the effective doses is 1 mSv/y and the maximum radium equivalent value is 370.0 Bq/kg for safety use as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3].

#### **1.5 Literature Review**

Many scientists worked in the field of analyzing samples to show the natural radioactivity by using gamma-rays spectroscopy system.

The radioactivity levels in Nasser Lake sediments over the time period 1992–2000 was presented and the distribution pattern of the measured radionuclides ( $^{238}\text{U}$  series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$ ). In addition, the uranium

concentration in water samples was measured. The distribution pattern of these radionuclides in sediments reflects the geochemical behavior and weathering processes of uranium series, thorium series and the heavy minerals in the Nile pathway and in Nasser Lake [4] .

Selected sedimentary samples from different locations on the east and west banks of the Nile River in Upper Egypt were analyzed by natural radioactivity measurements to detect the presence of radioactive elements. From the analysis of radiations from  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  isotopes, the samples were found to contain Ra, Th and K in concentrations up to  $52\pm 7.3$ ,  $76.2\pm 6.2$  and  $351.9\pm 17.6$  Bq  $\text{kg}^{-1}$ , respectively. The absorbed dose rate in air was found to be in the range of  $9.6\text{--}84.8$  nGy $\text{h}^{-1}$ . The representative external hazard index values for the corresponding samples were also estimated [5].

Sediment samples along the Upper Egypt Nile River region were collected starting from Aswan in the south to the north of El-Minia Governorate. Gamma radiation measurements were performed using high resolution HPGe detector with low background multichannel spectrometer. The gamma measurements of the alluvial sediments revealed the presence of the natural long-lived radioisotopes  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . The ranges of their activity concentrations were  $3.83\pm 1.54\text{--}34.94\pm 4.01$ ,  $2.88\pm 1.07\text{--}30.10\pm 1.83$  and  $112.31\pm 4.77\text{--}312.98\pm 12.24$  Bq $\text{kg}^{-1}$  respectively. The measured activity concentrations differ widely as their presence in the Nile River depends on the pertinent environmental situation such as the presence of dams, barrages and sediments type. Absorbed dose rates have been calculated for each location with range  $12.71\pm 0.96\text{--}38.17\pm 1.55$  nGh $^{-1}$ . Also the estimated activity utilization indexes have been presented. The ratios between the detected radioisotopes have been calculated [6].

In an attempt to understand the geochemical behavior of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  and the fallout nuclide  $^{137}\text{Cs}$  in aquatic sediments, surface sediments were collected from White, Blue and River Nile and fractionated into seven grain sizes (2000-1000, 1000-500, 500-250, 250-200, 200-125, 125-100 and  $< 100 \mu\text{m}$ ) and analyzed for the said elements using high-resolution gamma-spectrometry. Activity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the bulk samples display similar values in the three rivers. Results revealed clear inverse relationship between activity concentration and grain size in White and Blue Nile, while the trend is not clear in the River Nile. Activity concentrations of the respective radionuclides in different grain sizes indicated that White Nile sediments are more homogenous with respect to particle size as compared to Blue and River Nile. The activity concentration of the fallout radionuclide  $^{137}\text{Cs}$  in the bulk samples found to be ten times lower in the White Nile sediments ( $0.33 \pm 0.28$ )  $\text{Bq kg}^{-1}$  as compared to Blue Nile sediments ( $2.92 \pm 0.77$ )  $\text{Bq kg}^{-1}$  [7].

Radioactivity concentrations in sediment samples from Lake Naser and the surrounding area were measured, The average concentrations (ranges) of  $^{226}\text{Ra}$ ,  $^{228}\text{Ra}$ , and  $^{40}\text{K}$  were 20.6(4.0-48.0), 23.0(8.1-80.0) and 154.5(16.0-487.0)  $\text{Bq kg}^{-1}$  dry weight respectively [8].

Sediment samples from the Suez Canal were collected, there average activity concentrations for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were 10.7, 13.7, 114.6 and 1.6  $\text{Bq kg}^{-1}$  dry weight respectively [9].

A radiological study on the behavior of some radionuclides in sediments of Edku Lake was done. The mean specific activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were 13.6, 11.8, 288.4 and 4.4  $\text{Bq kg}^{-1}$  dry weight respectively [10].

The natural and artificial radioactivity levels in the sediments of Algiers were measured by using gamma ray spectroscopy. The ranges of concentrations of

$^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were 10.8-25.0, 6.5-31.7, 55.9-607.4 and 0.95-9.5  $\text{Bqkg}^{-1}$  dry weight respectively [11].

In Bulgaria determined the activity concentration of  $^{226}\text{Ra}$  in bottom sediment samples and it's found to be in the range of 3.0-77.0  $\text{Bqkg}^{-1}$  [12].

In France, the natural radioactivity in the french river sediments were studied . The mean values were 42.0-39.0, 28.0-46.0, 44.0-65.0 and 700.0-1150.0  $\text{Bqkg}^{-1}$  for  $^{238}\text{U}$ ,  $^{226}\text{Ra}$   $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively [13].

In Spain, the average activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were determined for many soil types. The radioactivity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in sedimentary soils were 42.0(13.0-100.0), 63.0(19.0-145.0) and 572.0(48.0-1176.0)  $\text{Bqkg}^{-1}$  dry weight respectively [14].

Soil samples were collected from different localities of districts Jhelum, Chakwal, Rawalpindi and Attock, Punjab Province, Pakistan with an aim to measure naturally occurring radionuclides, namely  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and fallout  $^{137}\text{Cs}$  radionuclide using a P-type coaxial high purity germanium (HPGe)  $\gamma$ -ray spectrometer. Measured specific activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in these soil samples ranged from  $26.02 \pm 7.11$  to  $93.54 \pm 8.13 \text{ Bq kg}^{-1}$ ,  $29.34 \pm 2.58$  to  $114.41 \pm 2.80 \text{ Bq kg}^{-1}$  and  $348.15 \pm 3.20$  to  $752.98 \pm 4.20 \text{ Bq kg}^{-1}$ , respectively. Activity due to  $^{137}\text{Cs}$  was observed in some locations which ranged from  $0.4 \pm 0.2$  to  $7.8 \pm 0.3 \text{ Bq kg}^{-1}$ . From the measured activity concentrations, radium equivalent activity concentrations were determined followed by calculations of mean absorbed dose rate and mean annual effective dose for the inhabitants of the studied area. The mean radium equivalent activity, internal and external hazard indices values came out to be  $179.26 \pm 11.93 \text{ Bq kg}^{-1}$ ,  $0.64 \pm 0.05$  and  $0.48 \pm 0.03$ , respectively. Indoors and outdoor average annual effective dose values were found to be  $0.42 \pm 0.03$  and  $0.10 \pm 0.01 \text{ mSv}$ ,

respectively. Present data have been compared with the published data for other parts of the world and found to be safe for public and environment [15].

Soil samples of radioactive concentrations of  $^{238}\text{U}$ -series ( $^{234}\text{Th}$ ,  $^{214}\text{Pb}$ , and  $^{214}\text{Bi}$ ),  $^{232}\text{Th}$ -series ( $^{228}\text{Ac}$ ,  $^{212}\text{Pb}$ , and  $^{208}\text{Tl}$ ) and  $^{40}\text{K}$  were analyzed. Three objectives were set: (1) activity levels by surface soil sampling at 0, 15, 30 cm depth, (2) dose rates of gamma radiation, radium equivalent, index hazard, and effective dose, and (3) ambient dose rates [16].

Total uranium content in soil and plant samples obtained from various areas in the Nile Delta was Determined . Samples taken from east and west of the delta, Suez canal cities and from the Alexandria region were analyzed using gamma spectroscopy and laser fluorimetry. Uranium was extracted from digested samples with methyl-isobutyl ketone and measured using a laser fluorimeter. The radium content of the same soil samples was determined using gamma spectroscopy. The uranium content of plant samples was determined using LF, the average uranium content in soil and plant was  $19.8$  and  $2.0 \text{ Bqkg}^{-1}$  respectively [17].

Soil and vegetation samples from 33 sites within the north western area of the River Nile delta in Egypt were selected. It has been analyzed for natural and man-made radioactivity. Gamma-ray spectrometric measurements were performed where Bi-214 and Pb-214 were used for U-238series determinations, while  $^{208}\text{Tl}$  and  $^{228}\text{Ac}$  were used for  $^{232}\text{Th}$ -series determinations. In addition, alpha-spectrometric measurements were also performed for the determination of different isotopes of uranium and plutonium. Other parameters examined included the determination of radium equivalent activities and relationship between the gamma-radiation values and subsequent dose level determinations and the soil types [18] .

The  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in surface soil in the Nile Delta, North coast and Middle Egypt regions have an average specific activity of 16.6, 18.1 and 316.0 Bq/kg dry weight respectively. The lowest activity concentrations of these radionuclides were found in sandy soil [19].

In Egypt, Lake Naser, the  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  concentrations in soil were 13.5, 14.0, 90.0 and 0.72 Bqkg<sup>-1</sup> dry weight respectively. The Data obtained from Asyut and Aswan indicated that the average activity concentrations of the  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were 17.2, 17.8, 307.0 and 0.95 Bqkg<sup>-1</sup> dry weight. The analysis of alfalfa samples showed that the  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  activities were 8.0, 9.1, 1537.0 and 9.7 Bqkg<sup>-1</sup> dry weights respectively [20].

The average activity concentrations of the  $^{238}\text{U}$  series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  in different soil samples collected from the north- east of Libya and North of Egypt were 31.9, 33.6, 535.9 and 11.4 Bqkg<sup>-1</sup> dry weight respectively, while the concentration of total uranium measured in drinking water samples was 9.68 mBqL<sup>-1</sup>, and the absorbed dose rate in air from external radiation had an average of 59.3 nGyh<sup>-1</sup>[21].

Surface soil samples were collected and their radioactivity was evaluated. The ranges of the activity concentration of the  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  were 4.6-63.5, 6.5-28.6 and 93.0-412.0 Bqkg<sup>-1</sup> dry weight respectively [22].

In Namibia, the average activity concentrations (ranges) of the  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in soil samples were 28.0(9.0-53.0), 31.0, 32.0(3.0-38.0) and 480.0(42.0-1100.0) Bqkg<sup>-1</sup> dry weight respectively. The equivalent dose rate in air from external radiation ranged from 0.08 to 0.2  $\mu\text{Gyh}^{-1}$ . with an average of 0.12  $\mu\text{Gyh}^{-1}$  [23] .



In order to assess the activity concentration of natural and anthropogenic radionuclides in the Charfassion Island, Bhola, Bangladesh, the upper level sediment samples were analyzed by using Broad Energy Germanium (BEGe) detector. Average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  were found  $16.82\pm 2.18 \text{ BqKg}^{-1}$ ,  $32.84\pm 2.56 \text{ BqKg}^{-1}$  and  $743.52\pm 22.07 \text{ BqKg}^{-1}$ . These results were used to calculate the radiation hazard parameters like radium equivalent activities ( $\text{Ra}_{\text{eq}}$ ), representative level index ( $\text{I}_{\gamma\text{r}}$ ). Representative level index is used to estimate the level of gamma radiation hazard associated with the natural radionuclides. Due to natural radionuclides in sediment, the effective annual outdoor dose in the study area is 0.07 mSv; which is within the accepted range 0.07 mSv and representative level index ( $\text{I}_{\gamma\text{r}}$ ) is also found to be  $0.94 \text{ BqKg}^{-1}$ . The findings from this research work would be useful to evaluate the population exposure from radionuclides in this island [24].

The concentration ranges of the natural radionuclide  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in soil were 15.0-164.0, 16.0-174.0 and 201.0-1350.0 Bq/kg respectively In Ustica Island ( Italy ) [25] .

$^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  analysis has been carried out in the soil samples collected from different locations of Jodhpur and Nagaur districts of Northern Rajasthan, India using gamma ray spectroscopy. The measured activity concentration ranges from  $13\pm 8$  to  $36\pm 9 \text{ Bq kg}^{-1}$ ,  $40\pm 9$  to  $71\pm 11 \text{ Bq kg}^{-1}$  and  $294\pm 125$  to  $781\pm 159 \text{ Bq kg}^{-1}$  with the mean value of  $24\pm 9 \text{ Bq kg}^{-1}$ ,  $55\pm 11 \text{ Bq kg}^{-1}$  and  $549\pm 141 \text{ Bq kg}^{-1}$  for  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ , respectively. The radium equivalent activity of all the soil samples ranges from 114 to  $157 \text{ Bq kg}^{-1}$  with an average value of  $141 \text{ Bq kg}^{-1}$ , which is lower than the safe limit  $370 \text{ Bq kg}^{-1}$  as set by the Organization for Economic Cooperation and Development. The total absorbed dose of all the investigated samples varies from 56 to  $77 \text{ nGy h}^{-1}$  with an average value of  $68 \text{ nGy h}^{-1}$ . The overall annual

effective dose ranges from 0.34 to 0.47 mSv with the average value of 0.41 mSv. The corresponding values of external and internal hazard index of all the soil samples ranges from 0.32 to 0.43 and 0.37 to 0.53 with an average value of 0.39 and 0.45 respectively. It was observed that the soil of Jodhpur and Nagaur districts is suitable for construction purpose without posing any health hazard [26].

Portable high-resolution gamma-ray spectrometry was carried out to determine the natural radioactivity levels in high volume surface water samples of the northern coast of Oman Sea, covering the coastal strip from Hormoz strait to Goatr seaport, for the first time. The water samples from 36 coastal and near shore locations were collected for analysis. Analyses on the samples collected were carried out to determine  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  contents. The concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in surface water samples ranged between 2.19 - 2.82  $\text{BqL}^{-1}$ , 1.66–2.17  $\text{BqL}^{-1}$  and 132.6–148.87  $\text{BqL}^{-1}$ , respectively. The activity profile of radionuclides shows low activity across the study area. The study also examined some radiation hazard indices. The external hazard index was found to be less than 1, indicating a low dose. The results of measurements will serve as background reference level for Oman Sea coastlines [27].

Soil samples were collected for contamination analysis In the Republic of Ireland, following the Chernobyl accident. The average activity concentrations of  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were 37.0, 60.0, 26.0 and 350.0  $\text{Bqkg}^{-1}$  respectively[28].

In Iran, different soil samples were taken for the measurements of the natural radioactivity in Iran. The ranges of the activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were 8.0-55.0, 6.0-42.0 and 250.0-980.0  $\text{Bqkg}^{-1}$  respectively. The

average calculated absorbed dose rates from terrestrial gamma rays in normal background areas was  $64.0 \text{ nGyh}^{-1}$  [29].

The concentrations of the natural radionuclides in sediments of the Osun River were determined using gamma ray spectrometer NaI(Tl) detector coupled to a Multichannel Analyzer for spectral analysis. A total of 106 sediment samples were collected from 25 locations spanning the whole length of the river course from Oke-Imesi Ridge, about 5km North of Efon Alaiye to Lekki Lagoon. Sampling locations were spread out over the five states that the river traversed. The number of locations per state was partly due to accessibility. Hazard indices were used to determine the suitability of the sediment samples for building in the context of radiological hazard. Results obtained showed that the mean concentrations of  $^{40}\text{K}$ ,  $^{238}\text{U}$ , and  $^{232}\text{Th}$  in the sediments varied between  $175.6 \pm 6.1 \text{ Bqkg}^{-1}$  in lower course to  $188.5 \pm 7.2 \text{ Bqkg}^{-1}$  in upper course,  $28.4 \pm 2.0 \text{ Bqkg}^{-1}$  in upper course to  $13.1 \pm 1.4 \text{ Bqkg}^{-1}$  in lower course and  $11.4 \pm 0.3 \text{ Bqkg}^{-1}$  in upper course to  $16.3 \pm 0.4 \text{ Bqkg}^{-1}$  in middle course. The mean radium equivalent varied between  $42.9 \pm 9.0$  and  $65.7 \pm 13.0 \text{ Bqkg}^{-1}$  while external hazard index ranged from  $0.1 \pm 0.1$  to  $0.2 \pm 0.1$ . The radium equivalent and external hazard index values were below the recommended international limits of  $370 \text{ Bqkg}^{-1}$  and 1.0, respectively [30].

Hundreds of surface soil samples were collected in the central region of Japan. The natural radioactivity concentration of the uranium series ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ), thorium ( $^{232}\text{Th}$ ,  $^{228}\text{Ra}$ ) series and  $^{40}\text{K}$  ranged from 5.0-130.0, 5.0-185.0 and 75.0-1400.0  $\text{Bqkg}^{-1}$  respectively. The soil with the highest activity has originated mainly from the weathering of granite. The soil content of  $^{238}\text{U}$ ,  $^{226}\text{Ra}$  and  $^{228}\text{Ra}$  increases with decreasing particle size [31].

The health hazard associated with concentrations of natural radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in soils of northern part of Pahang state Malaysia were determined. In situ measurement for external gamma radiation and soil samples was taken from different locations covering the entire districts of the study area. The in situ measurements were conducted using NaI[Ti] detector. The mean terrestrial gamma dose rate (TGDR) was found to be  $185 \pm 7 \text{ nGy h}^{-1}$ . The soil samples were measured using high-purity germanium detector (HPGe) and analyzed using Genie2000 software. The results obtained shows that the mean activity concentrations of the radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the area were  $117 \pm 4$ ,  $151 \pm 5$  and  $622 \pm 57 \text{ Bq kg}^{-1}$ , respectively. The Radium equivalent activities ( $R_{\text{eq}}$ ), External hazard index ( $H_{\text{ex}}$ ) and Annual Effective Dose (AED) out doors were also found to be  $380 \text{ Bq kg}^{-1}$ , 1.027 and  $0.210 \text{ mSv year}^{-1}$ , respectively. The results were compared with values given in United Nations Scientific Committee on the Effects of Atomic Radiation (2000)[32].

In China, the average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  were 39.8, 46.9 and  $567.0 \text{ Bq kg}^{-1}$  dry weight respectively. The total dose rate ranged from 52.4 to  $201.6 \text{ nSv h}^{-1}$ .with an average of  $98.4 \text{ nSv h}^{-1}$ [33].

Environmental survey and measurements of gamma radioactivity in the soil samples collected from Segamat District were conducted. Two gamma detectors were used for the measurements of background radiation in the area and the results were used in the computation of the mean external radiation dose rate and mean weighted dose rate, which are  $276 \text{ nGy h}^{-1}$  and  $1.169 \text{ mSv y}^{-1}$ , respectively. A high purity germanium (HPGe) detector was used in the assessment of activity concentrations of  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and  $^{40}\text{K}$ . The results of the gamma spectrometry range from  $11 \pm 1$  to  $1210 \pm 41 \text{ Bq kg}^{-1}$  for  $^{232}\text{Th}$ ,  $12 \pm 1$  to  $968 \pm 27 \text{ Bq kg}^{-1}$  for  $^{226}\text{Ra}$ , and  $12 \pm 2$  to  $2450 \pm 86 \text{ Bq kg}^{-1}$  for  $^{40}\text{K}$ . Gross alpha

and gross beta activity concentrations range from  $170 \pm 50$  to  $4360 \pm 170 \text{ Bq kg}^{-1}$  and  $70 \pm 20$  to  $4690 \pm 90 \text{ Bq kg}^{-1}$ , respectively. These results were used in the plotting of digital maps (using ARCGIS 9.3) for isodose[34].

Soil samples were collected around Lawrence Livermore National Laboratory In USA, and the average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were 30.0, 25.0, 470.0 and  $7.0 \text{ Bqkg}^{-1}$  dry weight respectively [35].

Concentrations of natural radionuclides ( $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) in ground and drinking waters of some areas were determined in Upper Egypt by gamma ray spectrometry with a HPGe detector setup, coaxial type and 8192 channels MCA. The investigated waters differed in radioactivity content depending on their origin and place. In drinking water in Qena, Upper Egypt, the mean  $^{226}\text{Ra}$  concentration was  $1.32 \pm 0.7 \text{ Bq L}^{-1}$ . In ground water in Safaga and Quseir, the Red Sea region, where there are phosphate mines,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  mean values were  $3.05 \pm 0.9$  and  $1.39 \pm 0.6 \text{ Bq L}^{-1}$ . A mean annual effective dose taken into the body by the population drinking this tap water may account for 0.008 mSv, which is lower than the limit recommended by the WHO [36].

## **1.6 Thesis Layout**

This work has come into four chapters. Chapter one spoke about research problem and aims, radioactivity stander levels and literature review. Chapter two spoke about radiation, the ecosystems, radionuclides, radiation exposure, biological effects of radionuclide contaminants and sampling techniques. Chapter three explained the experimental methods and theoretical calculations. Chapter four contained results, discussion, doses assessment and results conclusion.

# CHAPTER TWO

## THEORETICAL ASPECTS

### 2.1 Radiation

Radiation is the emission or transmission of energy in the form of waves or particles sent out over a distance in all directions. This includes electromagnetic radiation such as radio waves, visible light, gamma-ray and X-ray, Particle radiation such as  $\alpha$ ,  $\beta$ . There are two different types of radiation.

#### 2.1.1 Non-ionizing Radiation

Have lower energy levels and longer wavelengths. Examples include radio waves, microwaves, visible light, and infrared rays from a heat lamp. Our senses can detect some types of non-ionizing radiation: we can see visible light, and feel the burning effects of infrared radiation. Non-ionizing radiation is strong enough to influence the atoms it contacts, but not strong enough to affect their structure. For example, microwave radiation is used to heat the water in food by causing water molecules to vibrate.

#### 2.1.2 Ionizing Radiation

Have higher energy levels and shorter wavelengths. Examples include X-rays and cosmic rays. Ionizing radiation has enough energy to directly affect the structure of atoms of the materials, including human tissue (direct effect or indirect effect), which it passes through. Ionizing radiation can take two different forms: Electromagnetic waves and High-energy particles [37].

### **2.1.3 Source of Ionizing Radiation**

Sources of ionizing radiation are classified into natural and man-made sources [2]. The background radiation may change with the development of the nuclear and non-nuclear technological applications. Most of the time, these changes give an indication of contamination in time to interfere with appropriate measures. Some countries have taken the dose from natural radiation as a reference for radiation protection standards as natural radiation is the main source of exposure to human kind [ 38].

#### **A. Natural Radiation Sources**

Studies of natural radiation background and exposure of human-beings are of great importance, for practical and scientific reasons. Study of the natural radiation background and dose levels is essential for the purpose of establishing a radiological reference base line. This is the first step in any local or national monitoring program [38, 39].

In the term of population dose, the natural radiation sources are the most significant. They are considered as the main contributor to the population collective dose. The natural radiation background levels are characterized by steady level without high variation with time, and space except in some high radiation level areas. It is important to estimate the level of this contribution and to keep it under continuous review [2,38].

Natural radiation sources are classified into three components:

1. Cosmic rays.
2. Cosmogenic radionuclides.
3. Primordial radionuclides.



### 1. Cosmic Rays:

They are classified into primary cosmic rays and secondary cosmic rays. The primary cosmic rays are high energy radiation, coming from the outer space. They have the ability to penetrate the earth's atmosphere. Their components are:

- i. Primary galactic cosmic rays which are high energy, and smaller portion of electrons, photons and neutrons.
- ii. Primary solar cosmic rays consisting mainly of protons and alpha particles that are released during solar flares.
- iii. Secondary cosmic rays which are produced through the interaction of the primary cosmic rays with atoms in the earth's atmosphere. They consist of electrons, meson and other reaction products.

The cosmic rays are classified, according to the radiation type, into two components; neutron component and ionizing component (including the electromagnetic radiation, protons, electrons and others [2]).

### 2. Cosmogenic Radionuclides:

The major production of cosmogenic radionuclides results from the interaction of cosmic rays products with the atmospheric gases. These radionuclides have half-lives ranging from minutes to millions of years. The most important of these radionuclides are  $^3\text{H}$ ,  $^{14}\text{C}$ , and  $^7\text{Be}$ , and of minor importance are  $^{10}\text{Be}$ ,  $^{22}\text{Na}$ ,  $^{35}\text{S}$ , and  $^{39}\text{Cl}$ . The radionuclides concentrations are varied with the atmospheric latitude, longitude, and time. That depends upon their production rates, half-lives, physical form in the atmosphere, and the rates of atmospheric mixing and deposition on the earth's surface [40,41].

### 3. Primordial Radionuclides:

There are some radionuclides that have existed in soil and the earth's crust for a very long time ago. These radionuclides are considered as the main contributor to population dose from natural radiation sources [42]. The primordial radionuclides are classified into

- a. Series radionuclides
- b. Non-series radionuclides.

(a) Series primordial Radionuclides: The series group is headed by the parent radionuclides which decay in sequence to other radioactive nuclides with different half lives and different decay modes, and finally end as stable isotopes[40]. There are three natural series headed by Uranium-238, Uranium-235 and Thorium-232. They are shown in Figures (2.1), (2.2) and (2.3) respectively. They are known respectively as:

- Uranium-Radium series.
- Actinium series.
- Thorium series.

In terms of population dose, Uranium-235 series (actinium or actino-uranium series) is not significant because of the relatively shorter half-life of the Uranium-235 ( $7.1 \times 10^8$  year). The longest isotopic half life time of this series is six times shorter than that of Uranium-238 ( $4.5 \times 10^9$  years). Moreover, the abundance of Uranium-235 is 0.72 % while the abundance of uranium-238 is 99.28 %. These radionuclides undergo spontaneous fission in nature [40].

In the absence of physicochemical or biochemical processes, each of the three series attains a state of secular radioactive equilibrium. These processes could

induce separation of the progeny radionuclides because of inherent differences in chemical properties.

At secular radioactive equilibrium, the number of atoms of each nuclide is in the same proportion to the number of atoms of the nuclide at the head of the series, as their half lives proportion. Because of major differences in chemical properties that affect separation, rarely in natural environments or in the body, secular radioactive equilibrium is established amongst all members of the uranium and thorium series. The degree of equilibrium between any parent-daughter pair depends on the time elapsed since the initiation of some separation process subsequent to measurement and the kinetic of the processes acting to induce separation.

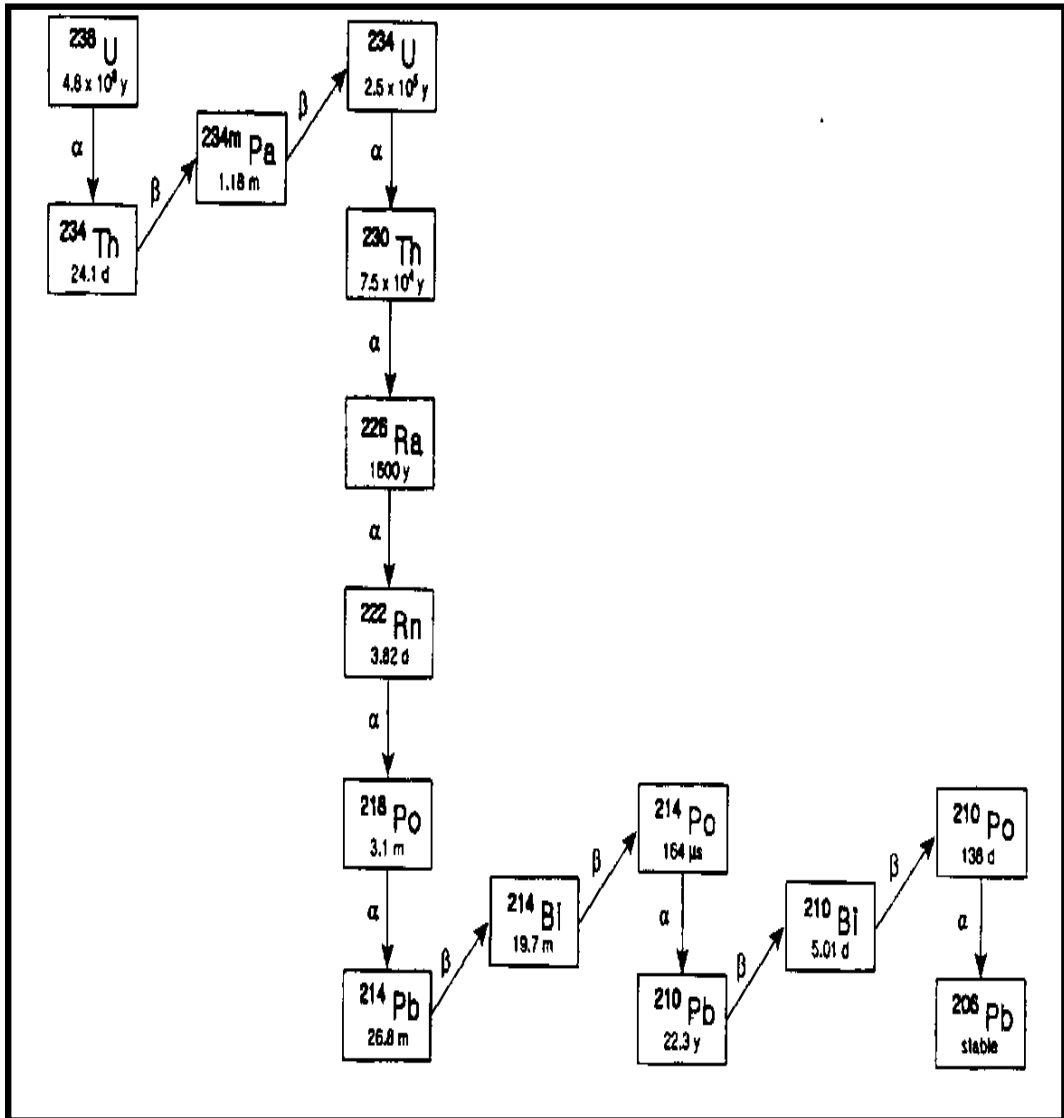


Fig (2.1): Uranium-238 series [43].

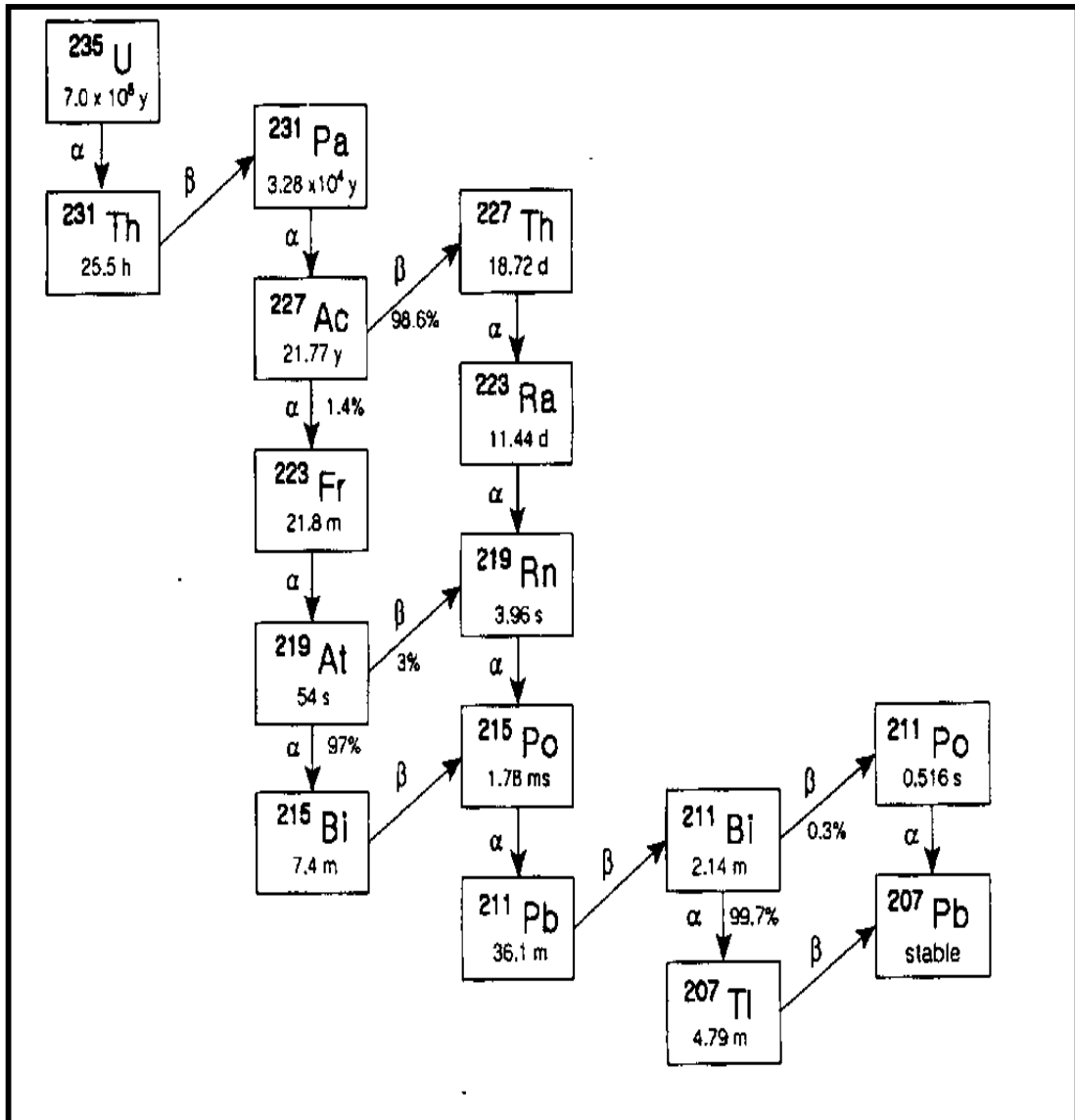
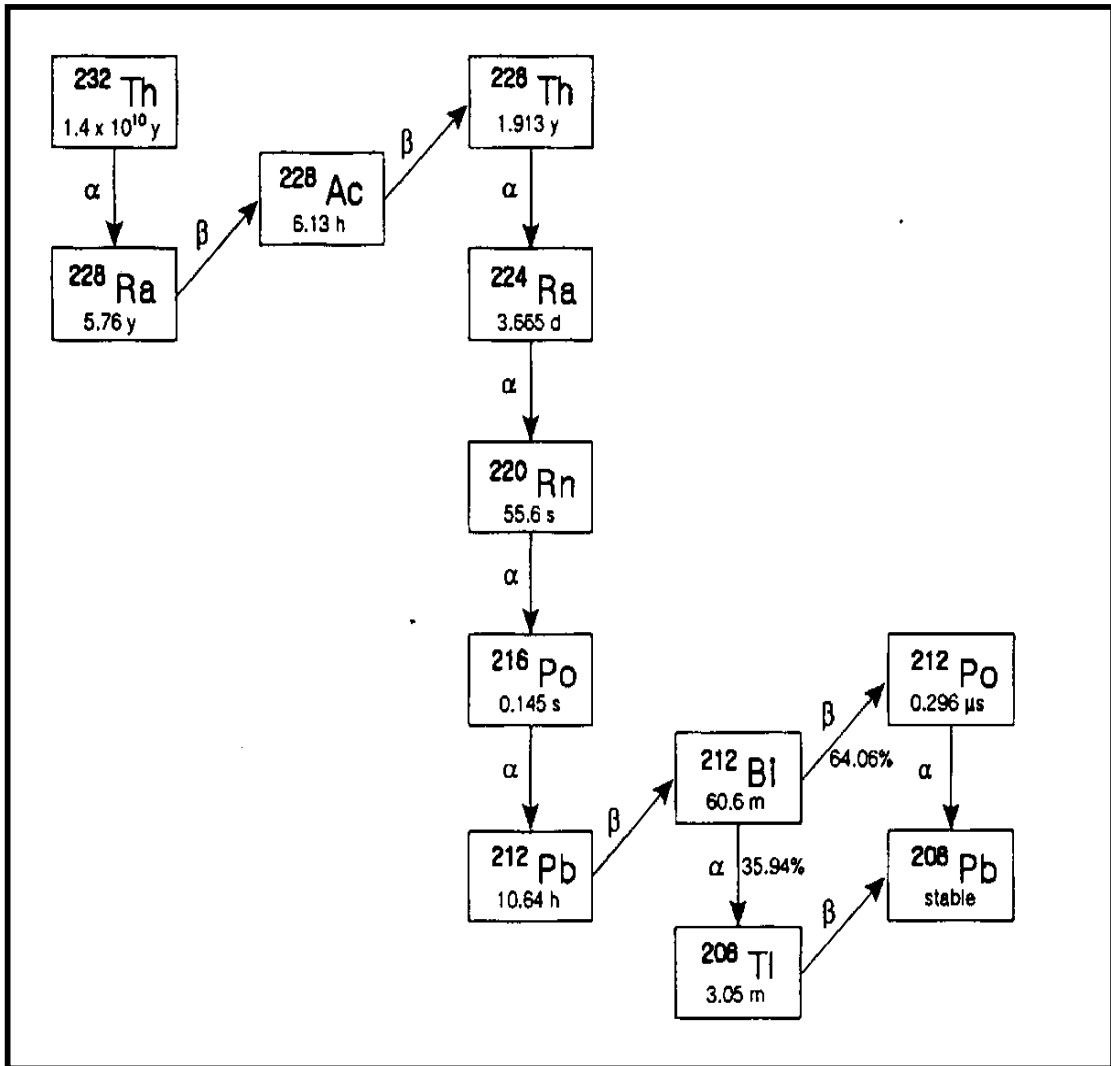


Fig (2.2): Uranium-235 series [43].



**Fig (2.3):** Thorium-232 series [43].

In most cases, daughter radionuclides within the thorium series are found in radioactive equilibrium in soils and those of the uranium series in near equilibrium, up to the formation of gaseous radon ( $^{222}\text{Rn}$ ). A fraction of the radon emanates from soils into the atmosphere resulting in disequilibrium in surface soils between  $^{226}\text{Ra}$  and  $^{210}\text{Pb}$  [40,44].

( b) *Non-series Primordial Radionuclides*: They decay directly to a stable nuclide. The most important radionuclides are the isotopes of Potassium ( $^{40}\text{K}$ ), Vanadium ( $^{50}\text{V}$ ), Cadmium ( $^{113}\text{Cd}$ ), and Indium ( $^{115}\text{In}$ ). In the term of population dose, the most significant radionuclides are  $^{40}\text{K}$  and  $^{87}\text{Rb}$ .  $^{40}\text{K}$  is a beta and gamma emitter, while  $^{87}\text{Rb}$  is only a beta emitter. Although, the isotopic abundance of  $^{87}\text{Rb}$  (27.85 %) is higher than that of  $^{40}\text{K}$  (0.0118%),  $^{40}\text{K}$  is more abundant in the earth's crust [40].

## **B. Man-Made Radiation Sources**

They are released from various man-made nuclear and non-nuclear activities. However, man-made radiation diffuses with time and from one place to another according to domestic, and/or world nuclear activities, and several other factors. These activities include the following [2] :

1. Nuclear tests.
2. Nuclear power plants, and manufacturing and reprocessing facilities.
3. Sources used for medical, industrial and agricultural applications.
4. Sources used for research purposes.

1-Nuclear test: After a nuclear explosion, the radioactive fission products settle out slowly and deposit on the earth's surface, a process known as the fallout. Most of the heavy radioactive products deposit in a zone surrounding the explosion place while light products move as a plume to other places. The radioactive fallout is strongly affected by the meteorological conditions (wind

direction and speed, rain, humidity, geographical structure and others). Therefore, radioactive contamination may arrive at different places of the earth with different concentrations [2].

2-Nuclear power plants: Through the normal operation of nuclear power plants, the release of radioactive materials is very limited and controlled. However, for total consideration, environmental contamination dose occur in the following steps [2]:

- Mining and milling of uranium ores.
- Conversion to various chemical forms.
- Enrichment of the isotopic content of uranium-235( in some cases ).
- Production of power in nuclear reactors.
- Disposal of radioactive wastes.

3- Medical uses of radiation: The uses of radiation sources in medicine are divided into diagnostic uses (such as X-ray examinations, nuclear medicine applications and many other diagnostic procedures); therapeutic uses (such as tumor treatment). The medical applications of radiation sources are considered the main contributor to population doses from man-made radiation sources. This may constitute about 20-25% of man-made radiation exposure.

The exposure to the natural sources is enhanced by the technological activities such as coal fired power plants, use of phosphate rock as fertilizer, air travel and other activities.



## **2.2 Ecosystems**

Ecosystem is the combination of the abiotic (non living- things like air, water and mineral soil) physicochemical environment and biotic (living -plants, animals and microbes) organisms. They are combined together to form an interrelated and interdependent system, that is, an ecological system or ecosystem. This interaction between the non living and living components is an important concept in understanding the effect of man's actions on this environment which can be described by radionuclide transport processes[42].

### **2.2.1 Geosphere**

The geosphere consists of the solid earth, including soil, geosphere refers to the solid parts of the Earth and is used along with atmosphere, hydrosphere, and biosphere to describe the systems of the Earth .The part of the geosphere that is directly involved with environmental processes through contact with the atmosphere.The geosphere can be regard as a system which has concentric boundaries that are the outer surface of solid earth and the discontinuity within the mantle. The lowest dense materials become segregated in the thin outer shell of the crust, while the denser iron and nickel settled towards the center of the earth to form the core. The outer boundary forms a complex interface with the atmosphere and hydrosphere. It is this environment in which life has evolved [45,46].

The soil is the upper part of earth's crust, formed as a result of rock's deformation by complex physico-chemical processes that include weathering decomposition, organic matter addition and water movement. The soil consists of minerals, organic matter, water and air. Percentages vary widely according to soil type, usage, and particle's size as shown in table (2.1) [47].

According to the surface soil inorganic mineral constituent (clay, silt and sand) percentage, the soil can be classified into the textural classes: sand, silt or clay [47]. The sand has a particle size from 60 $\mu$ m - 2 mm. It is composed mainly of primary minerals such as quartz. Silt has a particle size ranging among 2 $\mu$ -60 $\mu$ m and clay particle size less than 2 $\mu$ m [41].

Clays are extremely common and important in mineralogy. Furthermore, in general, clays predominate in the inorganic components of most soils and are very important in holding water and in plant nutrient cation exchange. All clays contain silicate and most contain aluminum and water. Clay is defined as a group of microcrystalline secondary minerals consisting of hydrous aluminum silicates of very fine grain size. Clays have sheet-like structures.

**Table (2.1) : Physical data of Soils**

Soil type	Diameter( $\mu$ m )	Particles/g	Surface area (cm <sup>2</sup> /g)
Sand	20-2000	10 <sup>4</sup>	23
Silt	2-20	6 x 10 <sup>6</sup>	454
Clay	<2	9 x 10 <sup>10</sup>	8 x 10 <sup>6</sup>

Many clays contain large amounts of sodium, potassium, magnesium, calcium, and iron, as well as trace quantities of other metals. Clays bind cations such as Ca<sup>2+</sup> , Mg<sup>2+</sup> , K<sup>+</sup> , Na<sup>+</sup> and NH<sub>4</sub><sup>+</sup>, which protect the cations from leaching by water but keep them available in soil as plant nutrients. [48].

### 2.2.2 Hydrosphere

The hydrosphere contains Earth's water (the liquid of life) and consists of three systems. These three systems refer to freshwater (aquatic), saltwater (marine), and brackish water (estuarine) environments. The estuarine ecosystem usually acts as a bridge between the other two environments, when rivers and streams flow into bays and other arms of the sea [42,48].

River composition varies with climate, local geological and the presence of large cities or intensive agriculture. Since the average residence time of river water is in the order of days, river composition can change rather rapidly in response to external conditions. Geologists agree that the process of dissolution of rocks by rivers, followed by transport to the sea, sedimentation, and recycling of water by evaporation have been going on for a very long time. So, a state of pseudo-equilibrium has been reached [46].

**Table (2.2):** An inventory of the earth's hydrosphere is given as following [49].

<b>Reservoir</b>	<b>Mass of water (kg)</b>	<b>Residence time (yr.)</b>
<b>Oceans</b>	$1.39 \times 10^{21}$	37600
<b>Ice</b>	$2.92 \times 10^{19}$	15000
<b>Ground water</b>	$8.30 \times 10^{18}$	-
<b>Lakes</b>	$2.30 \times 10^{17}$	6.2
<b>Atmosphere</b>	$1.30 \times 10^{16}$	0.028
<b>Rivers</b>	$1.25 \times 10^{15}$	0.0337

The chemical processes occurring when fresh water meets salt water (estuaries) are obscure because the chemical nature of most dissolved elements were rarely known. The estuarine waters, in which tidal action brings about mixing of salt and fresh masses of water, are of special importance because of their high biological productivity. Not only shellfish are frequently harvested in estuarine water in large quantities, but the waters also serve as the nursery grounds for many species of fish. The following processes were might expected to occur in or near estuaries [41, 42] :

1. Deposition of suspended mud, and flocculation of colloidal hydroxides,
2. Desorption of some species from particulate because of competition with higher concentration of ions in sea water
3. Dissociation of some humic complexes in a medium of higher ionic strength.

Vast areas of land, as well as lake and stream sediments, are formed from sedimentary rocks. The properties of these masses of material depend strongly upon their origins and transport. Water is the main vehicle of sediment transport, although wind can also be significant. Sedimentary materials may be carried by flowing water in streams as the following [50]:

1. Dissolved load form sediment-forming minerals in solution,
2. Suspended load form solid sedimentary materials carried along in suspension,
3. Bed load dragged along the bottom of the stream channel.

Removal of a radionuclide to sediments consists of two processes:

1. Deposition with sediment particles
2. Diffusion in pore water across the sediment-water interface [50].

## 2.3 Radionuclides in the Environment

### 2.3.1 Radionuclides in the Atmosphere

The natural radioactive gases in the atmosphere include  $^{14}\text{CO}_2$ , with a residence time of a few years, together with  $^{220}\text{Rn}$  (55 s) and  $^{222}\text{Rn}$  (3.8 day).  $^{222}\text{Rn}$  is an important source of its decay products,  $^{210}\text{Pb}$  and  $^{210}\text{Po}$  in atmospheric dust. The natural fall-out in rain and dry deposition lies in the range from  $1.5$  to  $8.9 \times 10^{16}$  Bq  $^{210}\text{Pb}/\text{yr}$ . plus from  $0.74$  to  $1.4 \times 10^{16}$  Bq  $^{210}\text{Po}/\text{yr}$ , this greatly exceeds the estimated  $2.6 \times 10^{13}$  Bq  $^{210}\text{Po}/\text{yr}$  released by burning coal. The residence time of these two nuclides in air is the same as that of atmospheric particles, i.e., about 10-25 days [46].

Nuclear bomb tests in the atmosphere have released not only large amounts of fission products, but also substantial amounts of radionuclides such as  $^{14}\text{C}$ ,  $^3\text{H}$  and  $^{55}\text{Fe}$ . They are formed by reaction of neutrons produced at the site of explosion. It is estimated that bomb tests have injected 2100 kg carbon-14 and 215 kg tritium into the atmosphere, and one of the few useful results of this injection has been the determination of residence times of carbon dioxide and water in the atmospheric reservoirs and the hydrosphere. The concentrations of the fission product  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  are about  $0.04$  mBq/m<sup>3</sup>[46].

### 2.3.2 Radionuclides in Rocks and Soil

The distribution of radionuclides and radiation characteristics of rocks are depending upon the geological history of the rock, and the abundance of the radioactive elements [46]. The radioactivity of rocks mainly caused entirely by  $^{40}\text{K}$ ,  $^{87}\text{Rb}$ , uranium, thorium and their decay products. Other radioactive species are present in amounts that are usually less than 0.1% of the total activity [46].

The average activity concentrations of radium, uranium, thorium and potassium in various rock types are given in table (2.3) [41].

**Table (2.3) :** Average radium, uranium, thorium and potassium content  
( Bq/kg) in various rock types

<b>Rock type</b>	<b><sup>238</sup>U(Bq/kg)</b>	<b><sup>226</sup>Ra (Bq/kg)</b>	<b><sup>232</sup>Th(Bq/kg)</b>	<b><sup>40</sup>K (Bq/kg)</b>
Igneous	1.3 (48.1)	1.3 (48.1)	1.3 (48.1)	22.0 (814.0)
Sedimentary				
Sand-stone	0.4 (14.8)	0.71 (26.3)	0.65 (24.1)	8.8 (325.6)
Shalles	0.4 (14.8)	1.08 (39.96)	1.1 (40.7)	22.0 (814.0)
Lime-stone	0.4 (14.8)	0.42 (15.54)	0.14 (5.18)	2.2 (81.4)

The radioactivity concentrations of some radionuclides (Bq/kg) in soil are given in table (2.4) [46].

**Table (2.4):**Radioactivity concentrations of some radionuclides in soil ( Bq/kg )

<b>Nuclide</b>	<b>Source</b>	<b>Concentration</b>
Cs-137	Bomb tests	63.0
K-40	Natural	440.0
Mn-54	Bomb tests	7.4
Ra-226	Natural	30.0
Th-232	Natural	37.0
U-238	Natural	24.0

The carbon-14 in soil is not all in equilibrium with atmospheric carbon dioxide, and its specific activity has been used to obtain residence times of various organic fractions in soils. Radioactivity is added to the soil when fertilizers are used, especially potassium salts or derivatives of rock phosphate, which is rich in uranium. The behavior of important fission products such as  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in soils is now reasonably well known.  $^{137}\text{Cs}$  is tenaciously retained by clays and penetrates soil profile slowly, while  $^{90}\text{Sr}$  is somewhat more mobile [41].

The soil type affects strongly the behavior of radionuclides in the soil, and soil retention characteristics. The sandy soil does not have the retention capacity of clay soils. Clay soils are composed of smaller particle size with larger surface area and negative charged surface. The soil's pH value affects the plants uptake. In alkaline soils (high pH) insoluble precipitates may be formed with carbonate, hydroxyl, phosphate or sulfide ions. These insoluble precipitates reduce the availability of radionuclides for plants. In acidic soils (low pH), the hydrogen replace the adsorbed cations which become more available to plants. In highly acidic soils (pH < 5.5) some of trace elements (particularly iron and manganese) may become toxic to plant growth [51].

### **2.3.3 Radionuclides in the Hydrosphere**

Hydrosphere includes the marine environment, rivers, streams, and lakes. The concentrations of naturally-occurring radionuclides in water are several orders of magnitude less than those in rocks and soils and are mostly due to  $^{40}\text{K}$ . In many natural waters, there is a significant shift away from equilibrium between parent and daughter nuclides in the uranium and thorium series. Elemental uranium and radon daughters are frequently observed in excess

concentrations in the water relative to radium, while radium and thorium are strongly concentrated in the bottom sediments [52].

The radioactivity of most sources of fresh water is very low, of the order of 50-500 Bq/m<sup>3</sup> (0.05-0.5 Bq/L). It is mostly due to potassium-40 and radium-226. Very rarely, natural spring waters contain much larger quantities of radium, and the highest concentration reported seems to be 26 Bq/L from Japan. Radioactive contamination of rivers has occurred locally as a result of both uranium mining and the processing of nuclear wastes [46].

The dominant natural radionuclides in soft tissues are <sup>40</sup>K and <sup>210</sup>Po. In hard tissues, <sup>14</sup>C, <sup>210</sup>P and uranium seem to be important. Although, the sea is a less radioactive environment than the land, marine organisms are subject to relative high radiation doses from internally absorbed alpha-emitters, specially <sup>210</sup>Po.

Table (2.5) gives some estimates of the amounts of various radionuclides in fresh waters [46].

**Table (2.5) : Radionuclides in fresh water**

<b>Radionuclides in fresh water</b>	<b>Concentration in Bq/m<sup>3</sup></b>
Cs-137	3.7-37.0
K-40	15-300
Pb-210	3.0-8.0
Ra-226	4.0-400.0
Rn-222	9.0
Th-232	0.12
U-238	48.0

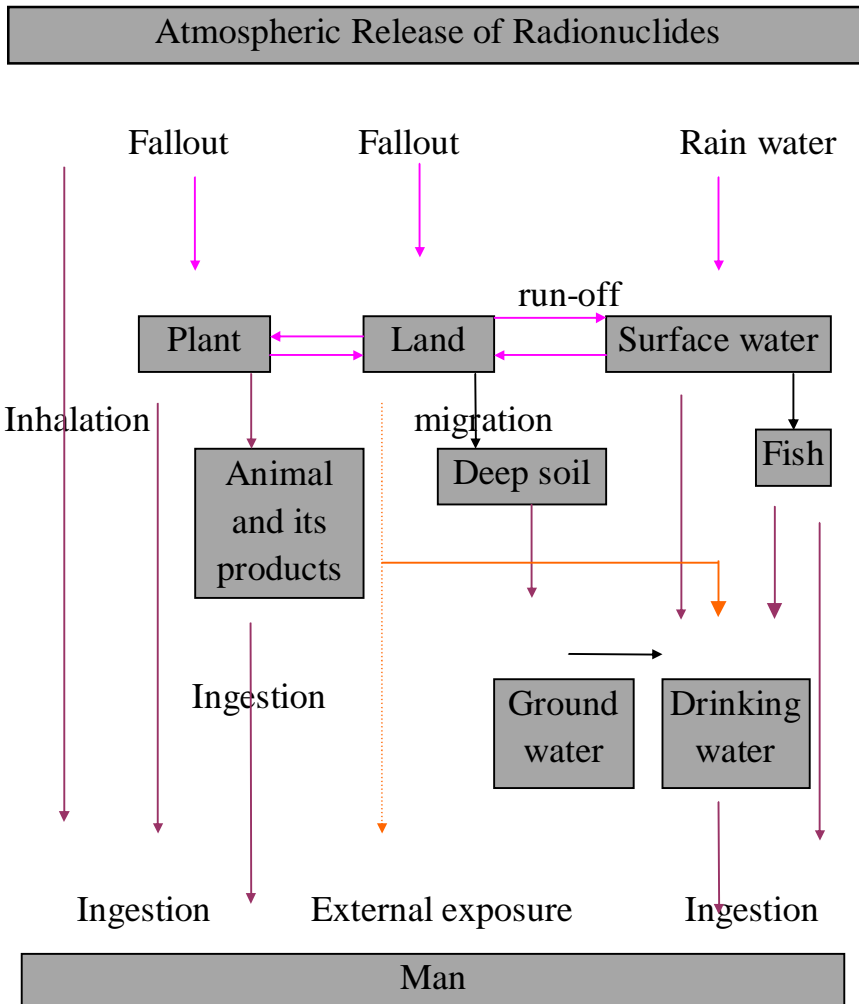


## 2.4 Environmental Behavior of Radionuclides

Human beings can be exposed to environmental radioactivity in a number of ways. When a  $\gamma$ -emitting substance is deposited on surrounding surfaces, the ambient radiation background will be increased. If the contaminant is initially airborne, the radioactive particles may be inhaled or may deposit on the skin. Particles deposited on surfaces can be resuspended by wind action or human activity and can then be inhaled. The most complex mechanisms are those that involve contamination of food chains [53].

The ways in which human exposure can occur are illustrated in Fig (2.4). The pathways are often more complex than shown, and the fine details of some of the transport mechanisms are not always understood. The environment is crisscrossed with physical, chemical, and biological pathways that link the biophysical and biochemical processes on which all organisms depend for their existence. There are subtleties that may increase the opportunities for human exposure, but there are also natural protective barriers [53].

The importance of ecological pathways was appreciated early in the development of atomic energy when it was found that the hazard to human being from airborne iodine was not due entirely to inhalation of the dust or vapor but rather involved a pathway of deposition on leafy surface such as forage or grass, followed by grazing of dairy cows and secretion of radio iodine in cows milk. Because a dairy cow grazes a large surface area, it absorbs more radioactive iodine by ingestion than by inhalation, and since the radio iodine is secreted with milk, it can in this way be passed directly to humans in a relatively concentrated form [53].



**Fig (2.4):** Major Pathways of Radionuclides to Man

## **2.5 Radiation Exposure**

Natural ionizing radiation arises in our space, where cosmic rays are formed, and in the earth, where radionuclides normally present in soil, air, water and food. Human exposure occurs by irradiation from sources outside the body (External exposure) and upon the decay of radionuclides taken into the body through ingestion and inhalation (Internal exposure) [54].

There are large local variations in the exposure depending on a number of factors, such as height above sea level, the amount and type of radionuclides in the soil of residence area (terrestrial exposure), the composition of radionuclides in air, food and drinking water and the amount taken into the body via inhalation or ingestion [55]. When ionizing radiation strikes a living organism's cells, it may injure the organism's cells. The organism may eventually develop cancer. Or at extremely high doses, it may even die [56].

### **2.5.1 Sources of Radiation Exposure**

The radiation to which we are exposed in everyday life comes from both natural and man-made sources. The most plentiful source of radiation to which people are exposed is from natural background, which includes cosmic radiation and the natural radioactive materials in the earth, atmosphere and our own bodies [51].

#### **A. Natural Sources Of Exposure :**

##### **1. Exposure from Terrestrial Radiation:**

The exposure of man to radiation that comes from terrestrial radionuclides in the earth's crust constitutes either external or internal exposure.

The external exposure from terrestrial radionuclides comes from gamma rays, which result from the decay of primordial radionuclides K-40, U-238 and Th-232 series. The external exposure results from outdoor and indoor exposure.

Outdoor exposures occur when gamma rays from decay of gamma emitting radionuclides present in soil reach man during his presence outside in free air or from cosmic rays. Indoor exposure results from inhalation of radon or thoron gases and their short lived decay products [57].

## 2. Exposure from Cosmic Rays

Cosmic rays which originate in space and solar particles enter the earth's atmosphere and begin a cascade of secondary interactions and decays. The resultant ionization is a function of both altitude and latitude. The cosmic rays at sea level is divided into two components, hard component (muons and few neutrons) and Soft component (electrons and photon radiation). The exposure to mankind from secondary cosmic radiation's and cosmogenic radionuclides reaching earth's surface constitute either from internal or external exposure [2].

### **B. Man-made sources of Exposure**

The remainder of the radiation we receive comes from man-made sources. This amounts to only about one-third of the amount received from natural sources (around 80mrem/y). By far the largest amount of radiation exposure from medical procedure. The dose received from all other man-made sources is much smaller than from natural sources or from medical procedures [51].

## 2.6 Biological effects of Radionuclide contaminants

### 2.6.1 Radionuclide contaminants

There are a relationship between chronic diseases and geologic environment. Geochemical environment is indeed a significant factor in the serious health problems. In the last 20 years, many people have suffered from these diseases that led to serious studies to find out the relationship between drinking water and chronic diseases Table (2.6) shows the EPA Standards of Radionuclides contaminants [58].

**Table (2.6):** EPA Standards of Radionuclides

<b>Contaminant</b>	<b>EPA standards</b>
Alpha emitters	15 pCi/L
Beta-particles	4 mrem
Photo emitters	4 mrem
Radium-226	20 pCi/L
Radium-228	20 pCi/L
Radon	300 pCi/L
Radium-226+228	5 pCi/L
Uranium	20 mg/L

## **Uranium:**

Potential health risks posed by depleted uranium and by uranium in general are attributable to two properties of uranium:

- Uranium is a heavy metal and as such chemically toxic (as are other heavy metals such as tungsten, lead, cadmium and mercury)
- All uranium isotopes are radioactive, i.e. they emit high-energy radiation during their spontaneous transformation and this radiation may have adverse biological effects. The chemical toxicity of a heavy metal is identical for all isotopes of the element. Since natural and depleted uranium differ only in their isotopic composition, they share the same chemical toxicity. Heavy metal compounds may cause a number of cytotoxic effects.

The half-life of uranium-238 is 4.5 billion years. The very long half-lives of these isotopes are the reason why uranium still exists on the earth. In a typical sample of natural uranium, almost all the mass (99.27%) consist of atoms of uranium-238. Less than 1% (about 0.72%) of the mass consists of atoms of uranium-235, and a very small amount (0.00055 % by mass) is uranium-234. Three additional isotopes (uranium-232, uranium-233, and uranium-236) are not naturally present but can be produced by nuclear transformations. These three isotopes also decay by emitting an alpha particle.

For uranium, the most important oxyanions in biological systems are carbonate/ bicarbonate compounds, e.g.  $[\text{UO}_2(\text{CO}_3)_2]^{2-}$ . While these compounds are stable at a neutral pH value (pH value of blood) and in this form are not very reactive, the highly reactive uranyl ion  $[\text{UO}_2]^{2+}$  is released at low pH values (as for example in urine) [59, 60].

Consequently, the kidney is the main organ affected by the chemical toxicity of uranium. As is the case with mercury, cadmium and other heavy metals, increased uranium levels lead to a reduction of glomerular filtration, the tubular secretion of organic anions and the reabsorption of filtered glucose and amino acids in the proximal tubules [46]. The severity of damage depends on the uranium level. A single inhalation of 8 mg of soluble uranium is regarded as the threshold level for transient kidney toxicity; persistent damage can be caused by 40 mg.

Today, the U.S. uranium industry considers 0.05 mg of soluble uranium per cubic meter of air and 0.25 mg of insoluble uranium as safe limits for the chronic exposure of workers. These values are expected to prevent uranium levels in the kidneys from exceeding 3  $\mu\text{g/g}$ . Germany, too, has established a maximum allowable concentration (MAC) of 0.25  $\text{mg/m}^3$ .

Publications from the early years of the uranium industry specify much higher exposure levels of up to 10  $\text{mg/m}^3$  at which there occurred no detectable health problems among workers.

Uranium radioactivity poses increased risks of lung and bone cancer. The damage caused by ionizing radiation from radionuclide transformations is largely a result of the energy absorbed by body tissues. Radiation doses are expressed in sievert (Sv), millisievert (mSv) or microsievert ( $\mu\text{Sv}$ ) (1 Sv = 1.000 mSv = 1.000.000  $\mu\text{Sv}$ ). The dose coefficient (Sv/Bq) denotes the relationship between the activity intake of a radioactive substance (in Bq) and the radiation dose caused by this substance.

**Radium:**

It seeks the bones when it enters the body. It is highly toxic and emits ionizing radiation. Radium is destructive to living tissue. Compounds formed with radium all have the same hazards as radium itself [60].

**Radon:**

Exposure to radon which is daughter from uranium series which is deposited in the lung and decayed into its daughter which have activity more than uranium by a factor of 10000 and the result is the lung cancer [61].

Potassium-40 is an important constituent of soil; it is widely distributed in nature and is present in all plant and animal tissues. Two stable (nonradioactive) isotopes of potassium exist, potassium-39 and potassium-41. With the concentration associated with sandy soil particles estimated to be 15 times higher than in the interstitial water [59].

**2.6.2 The Biological effects**

Ionizing radiation causes atoms and molecules to become ionized or excited. These excitations and ionizations can:

- Produce free radicals.
- Break chemical bonds.
- Produce new chemical bonds and cross-linkage between macromolecules.
- Damage molecules that regulate vital cell processes (e.g. DNA, RNA, proteins).

The radiation sensitivity of a tissue and organs are listed below from most radiosensitive to least radiosensitive [62]:



Most Sensitive: Blood-forming organs

Reproductive organs

Skin

Bone and teeth

Muscle

Least sensitive: Nervous system

The Radiation effects can be categorized by when they appear:

i. Prompt effects (Deterministic Effects): effects, including radiation sickness and radiation burns, seen immediately after large doses of radiation delivered over short periods of time. High doses delivered to the whole body of healthy adults within short periods of time can produce effects such as blood component changes, fatigue, diarrhea, nausea and death. These effects will develop within hours, days or weeks, depending on the size of the dose. The larger the dose, the sooner a given effect will occur [62].

Table (2.7) explains the doses and its prompt effect [63].

**Table (2.7):** The does and its prompt effect.

<b>Effect</b>	<b>Dose</b>
Blood count changes	50 rem
Vomiting (threshold)	100 rem
Mortality (threshold)	150 rem
LD50/60 (with minimal supportive care)	320 – 360 rem
LD50/60 (with supportive medical treatment)	480 – 540 rem
100% mortality (with best available treatment)	800 rem

- i. Delayed effects (Stochastic Effects) : effects such as cataract formation and cancer induction that may appear months or years after a radiation exposure [62 ].

**Cataracts:** Cataracts are induced when a dose exceeding approximately 200-300 rem is delivered to the lens of the eye. Radiation-induced cataracts may take many months to years to appear.

**Cancer:** Studies of people exposed to high doses of radiation have shown that there is a risk of cancer induction associated with high doses. The specific types of cancers associated with radiation exposure include leukemia, multiple myeloma, breast cancer, lung cancer, and skin cancer.

Radiation-induced cancers may take 10 - 15 years or more to appear. There may be a risk of cancer at low doses as well.

**Genetic Effects (Heredity effects):** There is no direct evidence of radiation-induced genetic effects in humans, even at high doses. Various analyses indicate that the rate of genetic disorders produced in humans is expected to be extremely low [62]. Table (2.8) explains the radiation effects categorized by when they appear.

**Table (2.8):** The radiation effects categorized by when they appear.

Characteristic of effects	Occurring time	Object	Effects on organs
Deterministic Effects	Acute Effects	Somatic Effects	Skin Damage
			Damage of reproductive system
Damage of blood forming system			
Damage of digestive system			
Stochastic Effects	Latent Effects	Somatic Effects	Damage of central nervous system
			Cataract
		Genetic Effects	Damage of immunization system
Stochastic Effects	Latent Effects	Genetic Effects	Cancer
			Heredity effects

## 2.7 Sampling Techniques

The purpose of environmental sampling and analysis is to obtain data which describe a particular site at a specific point in time from which an evaluation can be made as a basis for possible action. In this process, the collection of valid samples is the vital first step. Sampling should be done with the same care as the analysis, and both should be done with a rigor that is appropriate for the project at hand. In order for the data to be meaningful, sampling must be carried out with a clear purpose and with an understanding of the problem to be solved and the physical conditions that exist.

However, obtaining a representative measurement or sample of environmental parameters or materials is often not straightforward. Most environmental parameters and materials vary with location and time. For example, cosmic rays intensities vary with time, and various organs of plants and animals differ in their contents of organic and inorganic constituents. Soil typically contains particles of various sizes, and the chemical composition and surface reactivity of these particles often vary as a function of particle size. Water bodies, such as lakes and oceans, are commonly stratified, with variations in physical and chemical compositions from one layer to another, and usually have a surface film in which many reactive chemical constituents are strongly concentrated [64].

A variety of samples may be required for the purpose of establishing relationships between concentrations in the different matrices to further the understanding of dynamic processes. The number of sites sampled is determined by the purpose of sampling and the information required from the particular analysis.

The number of sites sampled is determined by the purpose of sampling and the information required from the particular analysis [64].

### **2.7.1 Examples of Common Sample Collection Designs**

Common sample designs can be subdivided into;

1. Cluster sampling designs.
2. Random sampling designs.
3. Judgmental sampling designs.
4. Regular or systematic sampling design.

Most statistical analysis requires a random sampling of the population. This means that all members of the population have an equal probability of being selected. This is usually achieved by designs when they are used on randomly distributed populations.

#### **1. Cluster Sampling Designs**

A cluster sample may taken at a given sample location. This type of sampling has the advantage of reduced collection cost for sampling. Since several samples are taken in proximity[65].

#### **2. Random Sampling Designs**

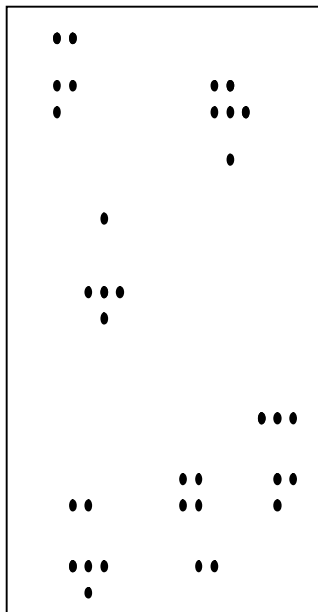
This design is usually accomplished by assigning a designator to each location, usually by coordinates, and randomly drawing locations to be sampled. This design is very versatile. It can be used for obtaining representative samples and determining mean values for an area, but it is not optimal for mapping an area since there is no way to guarantee a uniform distribution of samples across the study area [65].

### 3. Judgmental Sampling Designs

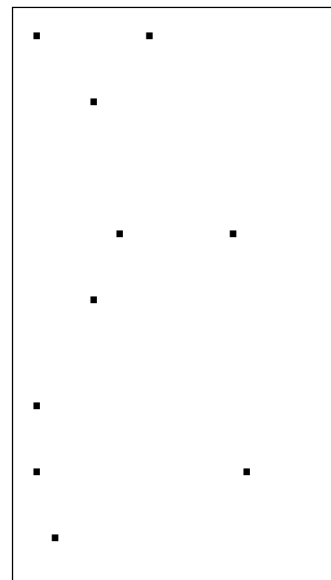
Judgmental sampling is a non-random process where the selection of samples is based on personal knowledge, bias, and any prior information. The effectiveness of this type of sampling is dependent upon the ability and knowledge of the researcher and cannot be quantified. Statistical treatment of the data acquired from this type of survey can be highly biased [65].

### 4. Regular or Systematic Sampling Design

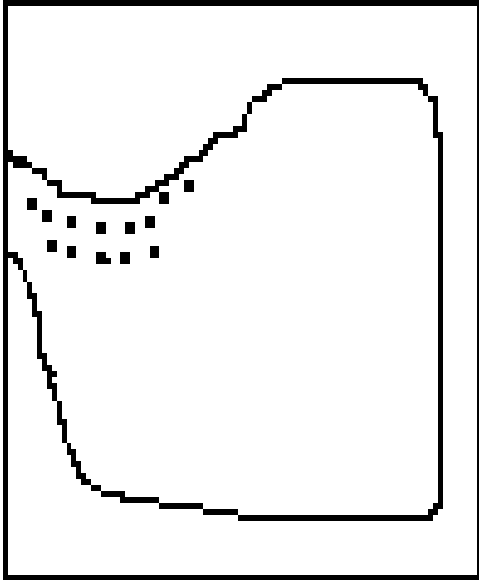
The grid sample design is one of the more common systematic designs. The design has also been systematic to a degree. If the starting location for a grid is picked arbitrarily, each of the members of the population will have an equal probability of being selected. A systematic design can be applied to transuranic contamination since it can be described as an intrinsic random function [65].



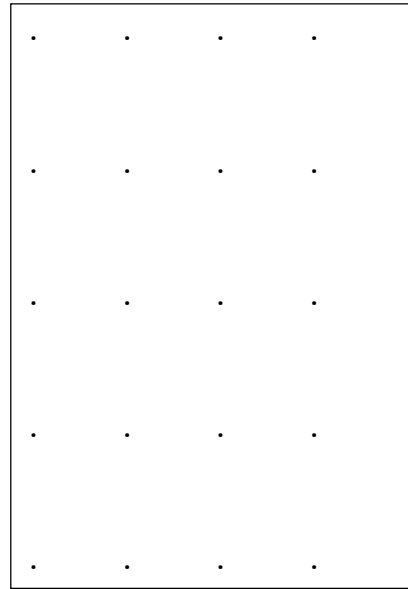
**Fig (2.5) : Cluster Sampling**



**Fig (2.6) : Random Sampling**



**Fig (2.7):** judgmental Sampling



**Fig (2.8) :**Systematic Sampling

# CHAPTER THREE

## EXPERIMENTAL TECHNIQUES

### 3.1 The Features of the Studied Area

The River Nile falls naturally into seven major regions: the Lake Plateau of East Africa, the Al-Jabal, the White Nile, the Blue Nile, the Atbara, the Nile north of Khartoum in Sudan and Egypt, and the Nile delta [66].

The two rivers White Nile and Blue Nile meet in the Sudanese capital of Khartoum (Almogran area) and from there it heads north winding its way through the deserts of northern Sudan into Egypt. The studied area start from Khartoum (Almogran area) to Halfa in northern Sudan . Below Khartoum, the Nile flows 50 Km northward until it reaches Sablwkah , the site of the sixth and highest cataract near Aljaily . Then the river cuts through hills for a distance until reach Shandy, its 105Km far from Khartoum. After that it is flowing northward to Atbara 310Km from Khartoum. Then the river takes an S-bend, it flows southwestward , the fourth cataract is in the middle of this stretch. At the end of this bend, it reach Dongola 530 Km far from Khartoum, it again resumes a northerly direction passing Wawa and janas until reach Wadee Halfa 909 Km from Khartoum [67,1]

The River Nile is the main source of water in the northern Sudan, flowing midway through the Sudan and divides its land, this natural set-up made it possible for a sedimentary society and a central authority to grow along the banks of that great river Nile [68] .



## 3.2 Sampling and sample preparation for measurements

### 3.2.1 Sample Collection

#### Sediments

Twenty four sediment samples were collected along the River Nile branch in northern Sudan from Khartoum (the capital of Sudan) to Wadie Halfa (the last town before the River Nile enter Egypt) Which is very long distance(909 Km) so the samples were collected according to population percentage (Town and Big village) from Khartoum , Aljaily , Shandi , Adbra , Dongola ,Wawa , Janas and Halfa. Table (3.1) and Map (3.1) show the location of samples.

**Table (3.1):** Show The Locations of Sediments Samples

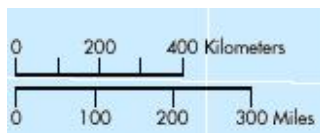
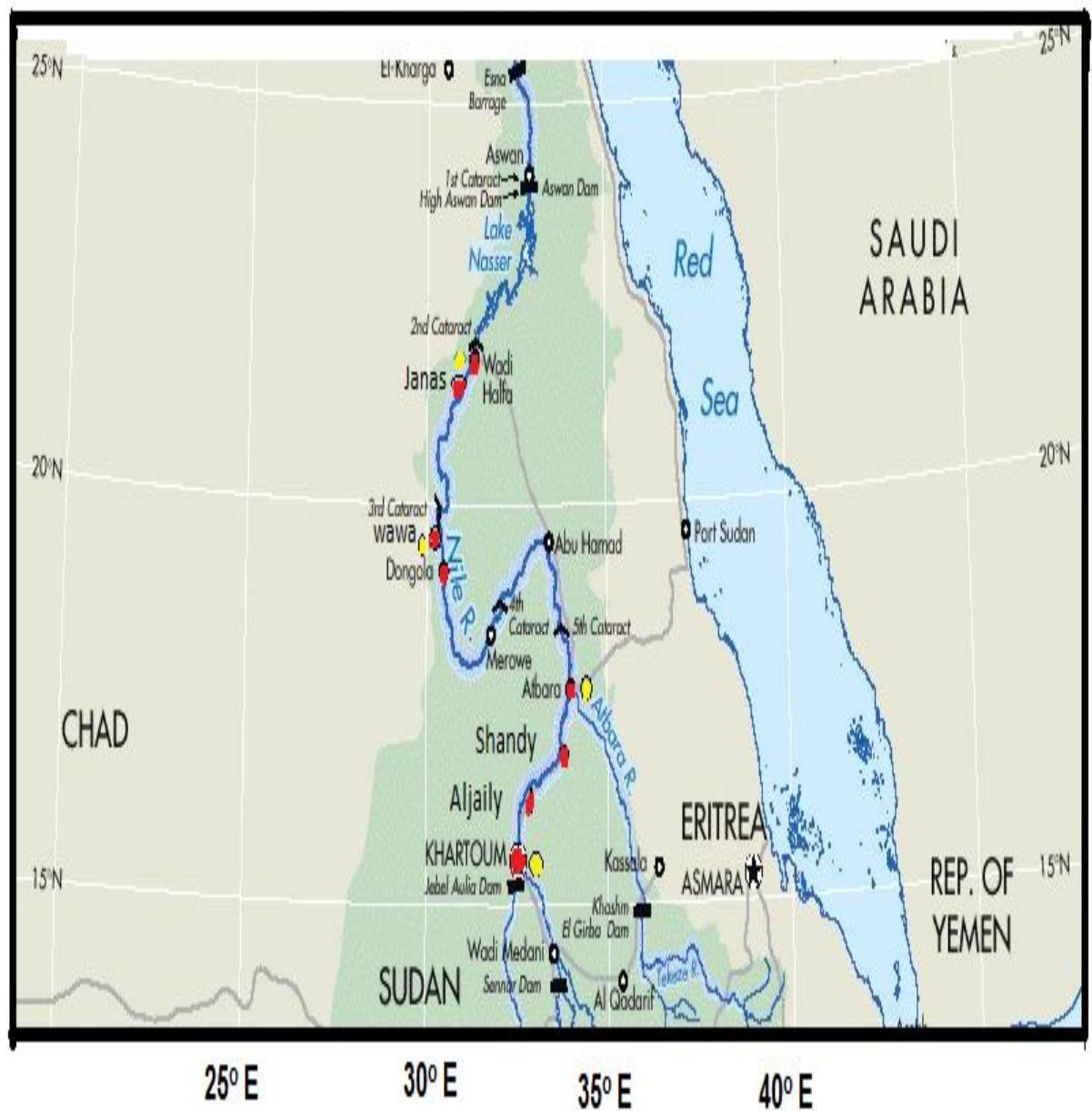
<b>N0</b>	<b>Town</b>	<b>Sample</b>	<b>Location</b>	
1	Khartoum	S <sub>11</sub>	15 <sup>o</sup> 37` 46` N	32 <sup>o</sup> 30` 26` E
		S <sub>12</sub>	15 <sup>o</sup> 42` 45` N	32 <sup>o</sup> 31` 28` E
		S <sub>13</sub>	15 <sup>o</sup> 47` 24` N	32 <sup>o</sup> 31` 53` E
2	Aljaily	S <sub>21</sub>	16 <sup>o</sup> 00` 06` N	32 <sup>o</sup> 34` 56` E
		S <sub>22</sub>	16 <sup>o</sup> 02` 34` N	32 <sup>o</sup> 35` 29` E
		S <sub>23</sub>	16 <sup>o</sup> 07` 18` N	32 <sup>o</sup> 35` 31` E
3	Shandy	S <sub>31</sub>	16 <sup>o</sup> 36` 56` N	33 <sup>o</sup> 24` 22` E
		S <sub>32</sub>	16 <sup>o</sup> 41` 20` N	33 <sup>o</sup> 26` 08` E
		S <sub>33</sub>	16 <sup>o</sup> 45` 42` N	33 <sup>o</sup> 28` 52` E

**Table (3.1) continued..**

<b>N0</b>	<b>Town</b>	<b>Sample</b>	<b>Location</b>	
4	Atbara	S <sub>41</sub>	17 <sup>o</sup> 46' 22" N	33 <sup>o</sup> 52' 08" E
		S <sub>42</sub>	17 <sup>o</sup> 53' 45" N	33 <sup>o</sup> 54' 26" E
		S <sub>43</sub>	17 <sup>o</sup> 60' 33" N	33 <sup>o</sup> 58' 35" E
5	Dongola	S <sub>51</sub>	19 <sup>o</sup> 11' 26" N	30 <sup>o</sup> 27' 66" E
		S <sub>52</sub>	19 <sup>o</sup> 14' 35" N	30 <sup>o</sup> 28' 12" E
		S <sub>53</sub>	19 <sup>o</sup> 16' 12" N	30 <sup>o</sup> 31' 11" E
6	Wawa	S <sub>61</sub>	20 <sup>o</sup> 20' 40" N	30 <sup>o</sup> 20' 32" E
		S <sub>62</sub>	20 <sup>o</sup> 24' 36" N	30 <sup>o</sup> 22' 02" E
		S <sub>63</sub>	20 <sup>o</sup> 27' 35" N	30 <sup>o</sup> 23' 27" E
7	Janas	S <sub>71</sub>	20 <sup>o</sup> 46' 45" N	30 <sup>o</sup> 27' 00" E
		S <sub>72</sub>	20 <sup>o</sup> 48' 00" N	30 <sup>o</sup> 27' 58" E
		S <sub>73</sub>	20 <sup>o</sup> 49' 08" N	30 <sup>o</sup> 28' 37" E
8	Halfa	S <sub>81</sub>	21 <sup>o</sup> 47' 32" N	31 <sup>o</sup> 20' 64" E
		S <sub>82</sub>	21 <sup>o</sup> 54' 46" N	31 <sup>o</sup> 22' 34" E
		S <sub>83</sub>	21 <sup>o</sup> 59' 06" N	31 <sup>o</sup> 30' 56" E

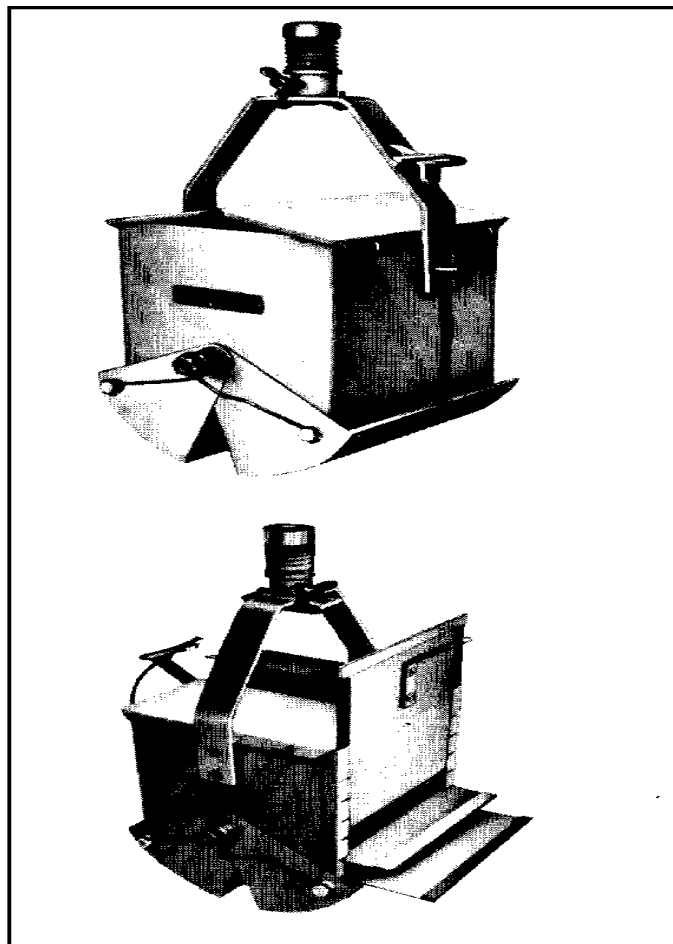
S: Sediments

**Map (3-1) The Locations of Samples**



- SEDIMENTS SAMPLE LOCATION
- WATER SAMPLE LOCATION

Various kinds of equipment can be used to obtain samples from the river Nile. These include grabbing devices, dredges, and coring devices. Grabbing devices, commonly known as snappers, vary widely in size and design. One general class of such devices is the clamshell snapper, which is used to obtain small samples of the superficial layers of sediments. Clamshell snappers come in two basic varieties. In this study a clamshell snapper was used, it measures 76 centimetres in length, weighs roughly 27 kilograms and is constructed of steel with a sampling surface of 1,000 cm<sup>2</sup>, Fig (3.1). It is equipped with messenger spring-closed jaws releases which automatically close-up when it touches the sediment surface [65]. It is suitable for soft and muddy sea or river soil.



**Fig (3.1):** Clamshell snapper (Sediment Samples collector)

Mechanical and physical analysis for the sediment samples:

Mechanical analysis is used to differentiate the inorganic mineral portion of soil into classified grades according to particle size and to determine their relative proportions by weight. The soil particles are classified according to their size into:

- Course sand with a diameter ranging from 200 to 2.000 microns.
- Fine sand with a diameter ranging from 20 to 200 microns.
- Silt with a diameter ranging from 2 to 20 microns and.
- Clay with a diameter of less than 2 microns.

In general, the procedure for determining particle size grades involve three stages:

- a. Removal or inactivation of cementing agents (mainly organic matter and calcium ion) and complete dispersion of soil sample in an alkaline medium (pretreatment).
- b. Separation of the course sand fraction by wet sieving.
- c. Determination of the silt and clay fractions in the dispersed sample by measuring the specific gravity with a special hydrometer [69, 70].

## Water

Four samples of 2 liters surface and subsurface water were collected along the River Nile branch in northern Sudan from Khartoum , Atbara , Wawa and Halfa , at the sediment sites, map(3.1) table (3.2), kept in clean polyethylene containers (they were washed successively with distilled water, , diluted acid before taking the samples), and acidified with 5 ml of conc. nitric acid to avoid radionuclides absorption on the container walls and growth of micro-organisms [71] .

**Table (3.2):** The Locations of waters Samples

NO	Town	Sample	Location
1	Khartoum	W <sub>1</sub>	15 <sup>0</sup> 42' 45" N      32 <sup>0</sup> 31' 28" E
4	Atbara	W <sub>4</sub>	17 <sup>0</sup> 53' 45" N      33 <sup>0</sup> 54' 26" E
6	Wawa	W <sub>6</sub>	20 <sup>0</sup> 24' 36" N      30 <sup>0</sup> 22' 02" E
8	Halfa	W <sub>8</sub>	21 <sup>0</sup> 54' 46" N      31 <sup>0</sup> 22' 34" E

W: Water

### 3.2.2 Preparation of the Samples for $\gamma$ -measurements by Gamma Spectrometry (GS)

Sediment or soil samples were prepared for analysis according to the following procedure:

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

For gamma spectroscopy measurement, the sediment samples, prepared as described above, were packed in Marinelli-type beakers (100 or 1000 ml capacity). Each sample was carefully sealed and stored for 4 weeks (this time is about seven half lives of  $^{222}\text{Rn}$   $T_{1/2} = 3.823\text{day}$ ) to reach secular equilibrium between  $^{226}\text{Ra}$  and its progeny [72].

The Water samples were evaporated to 1 liter on a hot plate to preserve all the radionuclides and after cooling they are transferred to Marinelli containers and sealed for 4 weeks to reach secular equilibrium between  $^{226}\text{Ra}$  and its progeny [72].

The activity of  $^{214}\text{Bi}$  and  $^{214}\text{Pb}$  in equilibrium with their parent were assumed to represent the  $^{238}\text{U}$ -series activity, while the activity of  $^{228}\text{Ac}$  and  $^{208}\text{Tl}$  were assumed to represent the  $^{232}\text{Th}$ -series activity [73].

### 3.3 Analytical Techniques

The prepared samples were analyzed for radioactivity concentration (gamma-measurements) by using Gamma spectrometry technique to performing quantitative and qualitative determination of radionuclides which emit gamma-rays.

The detection of natural gamma radiation is used to determine the concentration of radio-elements, potassium, uranium and thorium and the artificial radionuclide such as Cs-137. The detection of thorium and uranium depends on the assumption of secular equilibrium, where the rate of decay of the daughters becomes equal to the rate of decay of the parent [74].

The gamma lines; 351.9 keV (Pb-214), 609.3 keV (Bi-214), 1120.3 keV (Bi-214) and 1674.5 keV (Bi-214) were used for determining Ra-226 (daughter of uranium-238). The gamma lines 338.34 keV (Ac-228), 583.0 keV (Tl-208), 911.1 keV (Ac-208) were used for determining Th-232 series., while K-40 was measured by its gamma line 1460.7 keV.

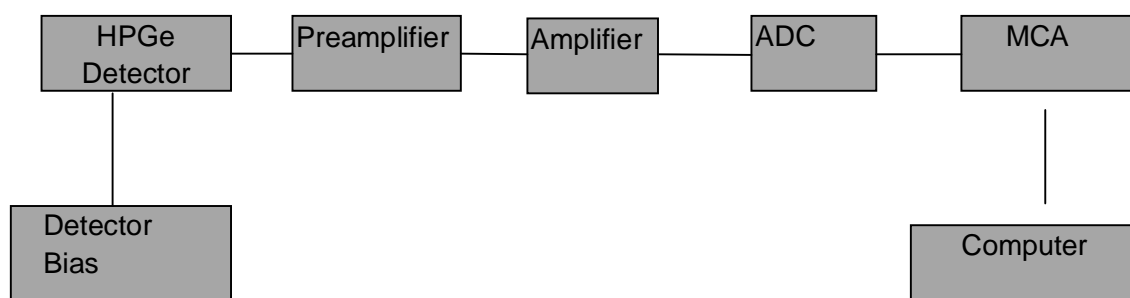
#### 3.3.1 Gamma Spectrometry

Gamma spectrometer fig (3.2) consists of :

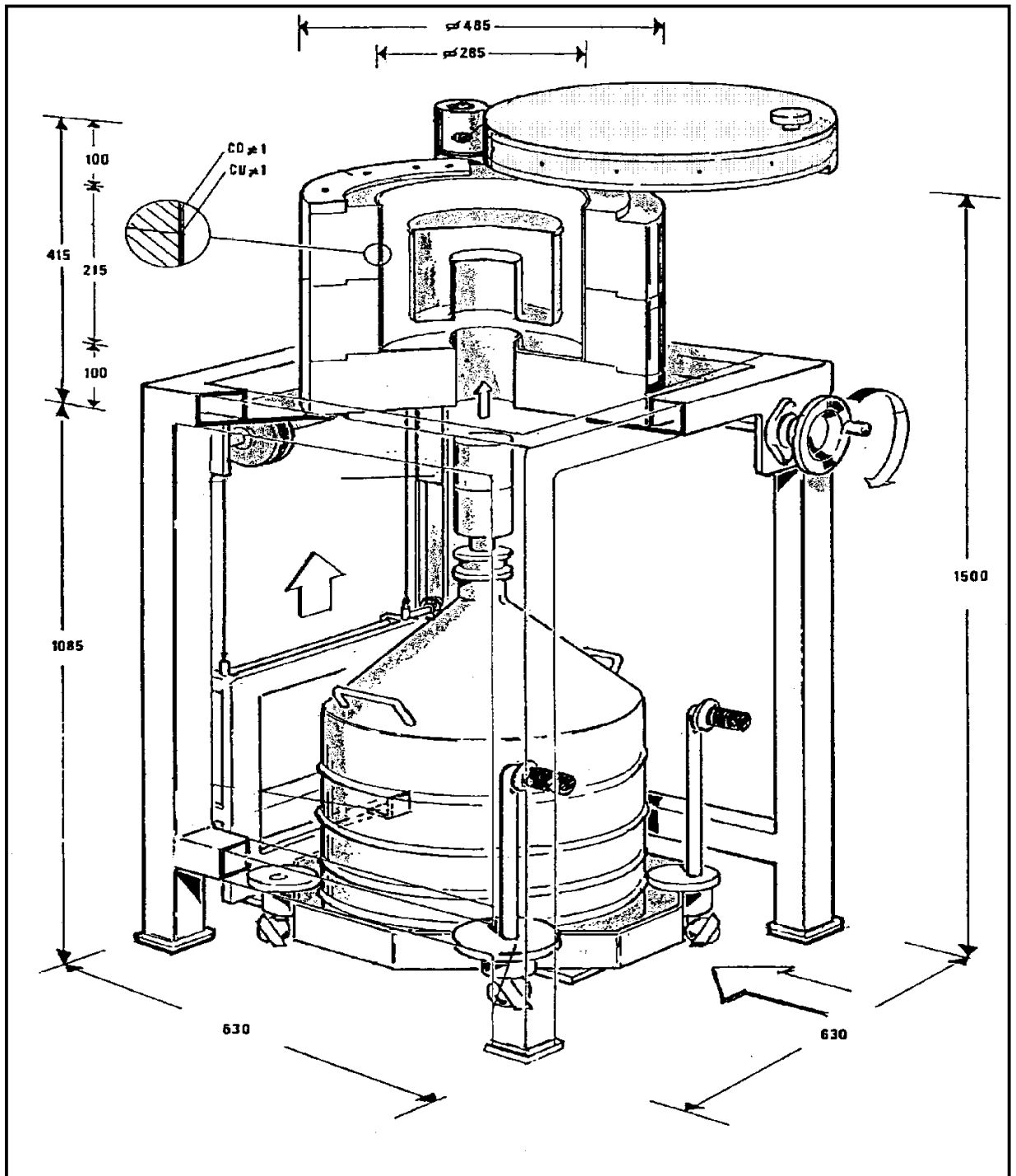
- A hyper pure germanium (HPGe) N-Type detector Canberra type type with relative efficiencies 40% and resolution 1.95 keV (FWHM) at 1.33 MeV of Co-60 gamma line of a vertical configuration, fig(3.3). The detector is mounted on a 30 liters liquid nitrogen dewar for the germanium crystal temperature control. The preamplifier is coupled to the detector and connected to the germanium crystal, so that its input components are kept at liquid nitrogen temperature ( 70°K) to reduce detector noises which reduces the leakage current generated by charge carriers at room temperature.



- High voltage power supply is designed to supply the detector with high voltage, with positive or negative polarity, with very low noise and very high voltage stability. All this is necessary to achieve the proper operation of a high resolution germanium detector.
- Bin and power supply (NIM standard) with  $\pm 6, \pm 12, \pm 24$  volt.
- A spectroscopy amplifier is an integral part of the low noise system. In addition to providing high amplifier gain, it provides shaping of the signal pulse to obtain the optimum signal to noise ratio consistent with the counting rate.
- An analog-to-digital converter (ADC) is utilized to obtain the ultimate in resolution, stability and linearity.
- A 8192 multichannel analyzer (MCA) with counting capacity of  $2^{28}-1$  counts per channel [75, 76].



**Fig (3.2):** Block diagram of gamma spectrometer set up



**Fig (3.3):** The arrangement of the HPGe detector with the lead shield

### 3.3.2 System Calibrations

Calibration process consists of Energy calibration and efficiency calibration.

i. Energy calibration :

The spectrometer was calibrated before any measurement applying the following standard gamma emitters,  $^{137}\text{Cs}$  (661.66 keV),  $^{60}\text{Co}$  (1173.23 and 1332.5 keV) and  $^{226}\text{Ra}$  in secular equilibrium with its respective progeny, with gamma ray lines shown in Tables (3.3), (3.4) It is thus clear that  $^{226}\text{Ra}$  is the most favorable standard source since its spectrum covers a wide energy range from 186 keV to 2.5 Mev [77]

In this work the standards Cs137, Co60, and Eu152 point sources where used for energy calibration and five gamma lines covering the whole energy range of the studied photopeaks , 121.78 keV, 344 keV, and 1408.02 keV (Eu152), 661.6 KeV (Cs137), 1173.24 keV (Co60) were used for energy calibration. . Then the energy calibration was done by least square fitting. These energy values were fitted to a third order equation of the following form:-

$$E = A_0 + A_1 N + A_2 N^2 + A_3 N^3 \quad (3-1)$$

Where;

E is the energy of the photopeak,

$A_0$  is the channel cut-off,

$A_1$  is the coefficient showing the linearity of the spectrometer,

$A_2$  and  $A_3$  or the coefficient showing the non-linear component, and

N is the channel number.

After getting the values of  $A_0$ ,  $A_1$ ,  $A_2$  and  $A_3$ , they were used to determine the energy of any unknown photopeak. The system automatically computes the peak barycenters and associates them with the energy values entered .

ii. Efficiency calibration:

The efficiency curve of the hyper pure germanium detector in the energy range from 186 keV to 2450 keV was obtained through two stages;

In the first stage the relative efficiency curve of the detector was obtained using a  $^{226}\text{Ra}$  point source. The most intensive gamma ray lines resulting from the decay of  $^{226}\text{Ra}$  in equilibrium with daughters ( Table 3.3) have been used.

The photopeak relative efficiency at certain energy was obtained from the formula [78].

$$\eta_{\text{rel}}(E) = \frac{I_d(E)}{I_{\text{ref}}(E)} \quad (3-2)$$

Where  $\eta_{\text{rel}}(E)$  is the relative efficiency at the energy E.

$I_d(E)$  is the relative intensity measured by the detector for the photopeak with energy E.

$I_{\text{ref}}(E)$  is the references relative intensity of the same photopeak.

**Table (3.3) :** Relative intensities of gamma rays from Ra-226 and its short-lived gamma daughters

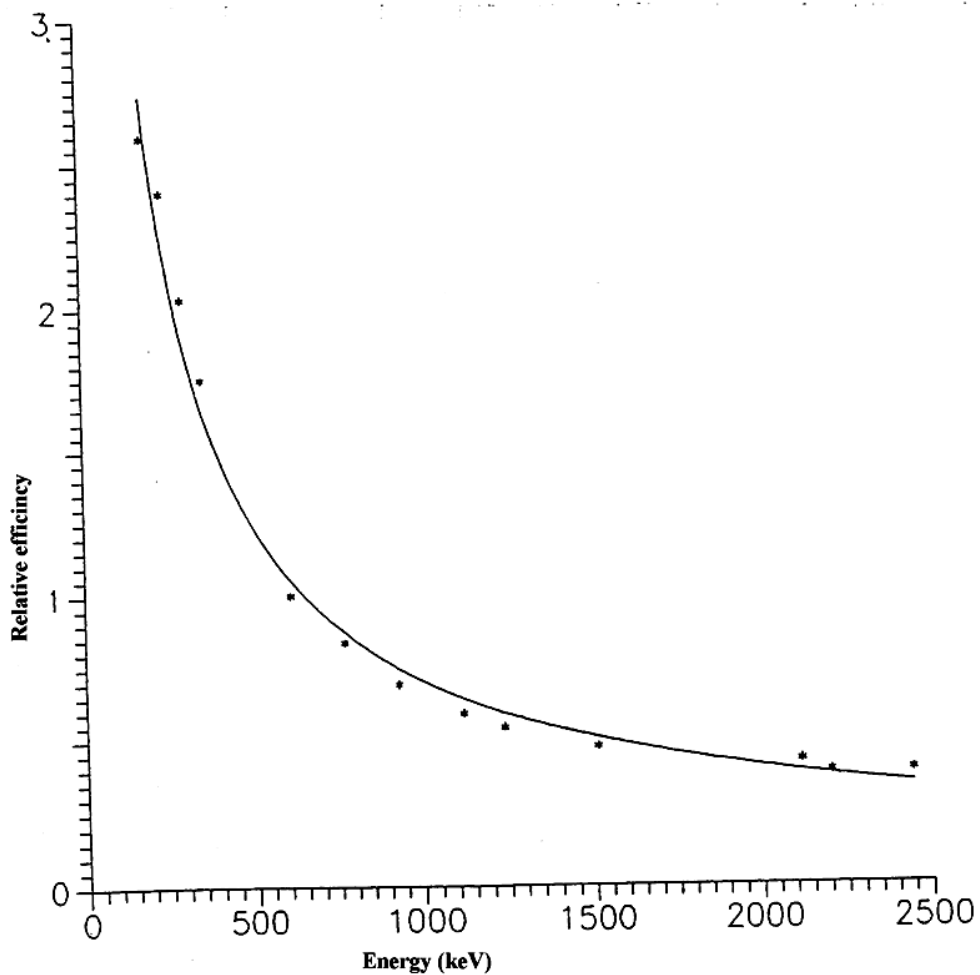
<i>Isotope</i>	<i>Energy ( keV)</i>	<i>Relative intensity</i>
Ra-226	186.18	9.07
Pb-214	241.92	16.53
Pb-214	295.22	42.52
Pb-214	351.99	81.29
Pb-214	609.31	100.0
Bi-214	768.36	10.64
Pb-214	934.06	6.54
Bi-214	1120.29	33.52
Bi-214	1238.11	13.25
Bi-214	1377.67	8.66
Bi-214	1509.23	4.77
Bi-214	1729.60	6.56
Bi-214	1764.50	34.91
Bi-214	1847.42	4.59
Bi-214	2118.50	2.51
Bi-214	2204.21	10.66
Bi-214	2447.81	3.28

**Table (3.4) :** The gamma transitions of some radionuclides

<i>Isotope</i>	<i>Energy ( keV )</i>	<i>Intensity%</i>
K-40	1460.7	10.7
Cs-137	661.6	85.0
U-238	Series :	
Pb-214	351.9	37.3
Bi-214	609.3	46.3
Bi-214	1120.3	15.0
Bi-214	1764.5	16.0
Th-232	Series :	
Ac-228	338.4	12.0
Tl-208	583.0	30.9
Ac-228	911.1	29.0
Ac-228	968.9	17.0

The relative efficiency curve of the detector was made for 17 different energy values covering the energy range from 186 keV to 2450 keV. The relative efficiency curve was obtained for two different positions. First, when the source was placed coaxially at 10 cm distance from the top surface of the detector and second, when the source was in the detector side at the same distance. The efficiency curve was plotted for both source positions. It was found that the two curves within a good approximation coincide in the energy range between 290 keV and 2450 keV. Slight difference was found at energies less than 290 keV. So, an average fitting curve, Fig (3.4) was made using both

results. The relative efficiency of the detector corresponding to any photopeak energy could be then obtained using this average curve.



**Fig (3.4):** Relative efficiency of Ra-226 and its daughter gamma lines

In the second stage the average relative efficiency curve of the detector was normalized to an absolute efficiency curve for a certain geometrical configuration [79]. Different types of Marinelli-type beakers and bottles were used to carry out present work (because of the variability of samples, their density, volume and matrix types), and normalization factor for these geometries "Marinelli-type beakers and bottles with the detector" have been determined. For this purpose standard solution of potassium chloride has been used.

Radioactive potassium-40 ( $\beta$ ,  $T = 1.28 \times 10^9$  years) exists naturally with the stable potassium-39 and potassium-41. Its natural abundance is 0.0118 % . So, using natural potassium, one can calculate exactly the amount of radioactive nuclides of  $^{40}\text{K}$  in the sample. One also can determine exactly the specific activity of  $^{40}\text{K}$  in any chemical form consisting of natural potassium. Pure KCl is an excellent low level reference source in many respects: environmental low level specific activity, wide availability at high purity and relatively simple branching decay.

The normalization of this study was done by using three different concentrations of KCl for each geometrical configuration [79]. The used concentration was 16 g/L, 32 g/L, 64 g/L, and 128 g/L, which correspond to  $261.8 \text{ BqL}^{-1}$ ,  $532.6 \text{ BqL}^{-1}$ ,  $1047.2 \text{ BqL}^{-1}$ , and  $2094.4 \text{ BqL}^{-1}$  respectively. The normalizing factor for any radionuclides was calculated relative intensities of gamma-ray photopeaks of this radionuclide and that of potassium as well as the percentage of photon per disintegration which is given by IAEA (1989) at Table (3.4). Normalizing factor (N.F.) for radionuclide (Y) is given by:



$$N.F(Y) = \frac{R.E(1460keV) \times P.D(K)}{R.E(Y) \times P.D(Y)} \times N.F(K) \quad (3.3)$$

Where

R.E (1460keV) is the relative efficiency of  $^{40}\text{K}$

R.E (Y) is the relative efficiency of radionuclide (Y)

P.D (K) is the percentage of photon per disintegration of  $^{40}\text{K}$

P.D (Y) is the percentage of photon per disintegration.

N.F (K) is the normalizing factor of  $^{40}\text{K}$ .

To calculate the concentration of natural radionuclides;  $^{40}\text{K}$ ,  $^{238}\text{U}$  series and  $^{232}\text{Th}$  series; the gamma transition of 1460 keV was used to represent  $^{40}\text{K}$ , for the gamma transition of 351.99 keV ( $^{214}\text{Pb}$ ), 609.3 keV ( $^{214}\text{Bi}$ ), 1120.3 keV ( $^{214}\text{Bi}$ ) and 1764.5 keV ( $^{214}\text{Bi}$ ) were used to represent  $^{238}\text{U}$  series and for  $^{232}\text{Th}$  series, the gamma transitions of 338.4 keV  $^{228}\text{Ac}$  and 583 keV  $^{208}\text{Tl}$  and 911.1 keV  $^{228}\text{Ac}$  were used. Also, to calculate the concentration of man-made radionuclides ( $^{137}\text{Cs}$  and  $^{134}\text{Cs}$ ), the gamma transitions of 661.6 and 604.1 keV were used respectively. The branching ratio (photopeak density) of each peak was taken into consideration in the activity calculations. The spectrum of these transition is shown in Fig (3.4).

The quality control of this method has been carried out for different environmental standard samples [79].

## 3.4 Theoretical Calculations

### 3.4.1 Error Calculations

Generally there are two types of errors; systematic errors (errors are associated with a flaw in the equipment or in the design of the experiment) and random or statistical errors (Errors that can be reliably estimated by repeating measurements). There are no strict definition of systematic errors, since a systematic error for one experiment may not be the same for another. Very often they are constant or at least change very slowly over the time required to make a single measurement.

The main sources of errors in the low level radioactivity measurement could be due to background, photopaek area calculation and statistical errors. The area calculation i.e. computes the number of counts within a peak (region of interest) (ROI) that are above a specified background level. The background level is determined by averaging (n) points on either side of the peak (outside the selection ROI) to determine the average background level. The total error  $\sigma_t$  was calculated from the following equation [80]:

$$\sigma_t = \sqrt{\sigma_1^2 + \sigma_2^2} \quad (3.4)$$

Where:  $\sigma_1^2$  is the error due to area calculation

$\sigma_2^2$  is the standard deviation of the determined activity.

### 3.4.2 Absorbed Dose Rate and Effective dose rate in Air from External Gamma Radiation

Exposure to gamma rays from natural radionuclides in free air is dependent on several factors, such as distribution of the radioactivity, moisture and density of the ground. The gamma radiation field was approximately calculated for

a height of 1 meter above the ground surface in each location using the following equation [3,81] :

$$D = R_k C_k + R_u C_u + R_{Th} C_{Th} \quad (3.5)$$

Where: D is the absorbed dose in nGyhr<sup>-1</sup>.

R<sub>k</sub>, R<sub>u</sub>, R<sub>Th</sub> are the conversion factors, expressed in nGyhr<sup>-1</sup>.per Bqkg<sup>-1</sup>, and are given in table (3.5) for some radionuclides.

C<sub>k</sub>, C<sub>u</sub>, C<sub>Th</sub> are the concentration of <sup>40</sup>K, <sup>238</sup>U series and <sup>232</sup>Th series respectively, expressed in Bqkg<sup>-1</sup> dry weight soil. [3,81].

Less than 84 nGyh<sup>-1</sup>.

**Table (3.5) :** Conversion factors for gamma ray 1 m above the ground  
Of natural radionuclides

<b>Radionuclide</b>	<b>Conversion factor ( nGyhr<sup>-1</sup>.per Bqkg<sup>-1</sup>)</b>
<sup>40</sup> K	0.043
<sup>238</sup> U series	0.662
<sup>232</sup> Th series	0.427

To estimate the annual effective doses, one has to take into account the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor [3,82,83] the Committee used 0.7 Sv Gy<sup>-1</sup> y<sup>-1</sup> for the conversion coefficient from absorbed dose in air to effective dose received by

adults, and 0.8 for the indoor occupancy factor. The effective dose rate indoors, in units of mSv per year, is calculated by the following formula:

$$E = D \cdot T \cdot Q \cdot Q_f \cdot 10^{-6} \quad (3.6)$$

Where

E= Effective dose rate (mSv y<sup>-1</sup>) ,

D= Dose rate (nGy h<sup>-1</sup>).

T=Time in hours =24 h .365.25 d

Q= conversion coefficient= 0.7 Sv Gy<sup>-1</sup> y<sup>-1</sup>

Q<sub>F</sub>= Occupancy factor=0.8

The value for the annual effective dose rate in mSv/year adequately falls within the permissible dose equivalent limit of 1mSv/year [84] .

### 3.4.3 Radium Equivalent Activity

The concentration and distribution of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K in the environmental samples is not uniform through the world. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity Ra<sub>eq</sub> in Bq/kg to compare the specific activities of samples containing different amounts of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K. This index is defined as :

$$Ra_{eq} = C_{Ra} + 10 / 7 C_{Th} + 10 / 130 C_K \quad (3.7)$$

where : C<sub>Ra</sub> , C<sub>Th</sub> and C<sub>K</sub> are the specific activities of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K in Bqkg<sup>-1</sup>, and this formula is based on the estimation that 1 Bq/kg of <sup>226</sup>Ra, 0.7 Bqkg<sup>-1</sup> of <sup>232</sup>Th or 13.0 Bqkg<sup>-1</sup> of <sup>40</sup>K produce the same gamma dose rate [85,86]. This value is much less than the upper limit of 370 Bqkg<sup>-1</sup> [3,82] .

# CHAPTER FOUR

## RESULTS AND DISCUSSION

### 4.1 Introduction

The present study aims to establishing baseline data by study and evaluation of radionuclides in the collected samples from selected areas in north Sudan Nile banks. The reasons for the choice of the radionuclides investigated are their significance contribution to the dose commitment so the results obtained in this study help in the radiological monitoring and assessment of radionuclides present in the River Nile, and the dose received by man from the Nile environment can be estimated . Also to adjust a system for identification of real changes in the radioactivity levels in the River Nile environment and to correlate this data with the occurrence of any accidental radioactive releases, and to know pollution effects on man and his environment by compare the result obtained with the world permissible standards.

In this chapter, the Gamma spectrometry of the sediment and water samples to be represented.

## 4.2 The Activity Concentration of Radionuclides in the River Nile Environment's samples

### 4.2.1 The Activity Concentration of Radionuclides in Sediments Samples

Measurements of terrestrial radionuclides  $^{226}\text{Ra}$  of ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$ , and  $^{137}\text{Cs}$  have been carried out for the collected sediments by using gamma spectrometry as shown in table (4.1) .

**Table (4.1) :** The Gamma Activity (Bq/kg) of Radionuclides in Sediments Samples

Town	Sample	U-238 series(Ra-226)	Th232 series(Ra-222)	K-40	Cs-137
1-Khartoum	S <sub>11</sub>	19.98±2.2	24.21±2.38	367.62±12.96	< DL
	S <sub>12</sub>	12.89±2.35	21.39±2.62	338.20±14.37	< DL
	S <sub>13</sub>	28.82±2.66	25.52±2.69	524.57±14.75	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
2-Aljaily	S <sub>21</sub>	28.52±1.73	31.89±1.70	349.22±16.45	< DL
	S <sub>22</sub>	28.52±1.10	31.89±2.59	371.94±13.83	< DL
	S <sub>23</sub>	25.74±2.31	32.38±2.87	532.22±14.39	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
3-Shandy	S <sub>31</sub>	18.58±0.92	20.09±1.65	332.26±11.93	< DL
	S <sub>32</sub>	19.78±0.90	22.23±1.97	356.56±12.36	< DL
	S <sub>33</sub>	19.78±0.3	20.51±1.7	356.56±12.36	< DL



**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
4-Atbara	S <sub>41</sub>	21.72±2.54	21.67±2.37	466.63±13.20	< DL
	S <sub>42</sub>	16.06±1.81	20.05±1.68	312.87±13.69	< DL
	S <sub>43</sub>	17.28±3.05	20.67±2.30	493.12±12.22	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
5-Dongola	S <sub>51</sub>	21.96±2.06	24.89±1.81	366.07±12.94	< DL
	S <sub>52</sub>	24.97±1.00	25.50±1.80	376.30±12.96	< DL
	S <sub>53</sub>	23.50±0.98	24.06±1.75	375.50±12.16	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
6-Wawa	S <sub>61</sub>	21.80±3.07	23.53±2.70	533.27±13.97	< DL
	S <sub>62</sub>	21.56±1.91	24.54±2.38	508.49±12.92	< DL
	S <sub>63</sub>	19.51±0.88	17.53±1.57	332.75±11.40	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra-222)</b>	<b>K-40</b>	<b>Cs-137</b>
7-Janias	S <sub>71</sub>	20.53±2.84	19.49±2.32	449.94±12.50	< DL
	S <sub>72</sub>	21.54±2.01	19.92±1.98	490.55±11.31	< DL
	S <sub>73</sub>	19.42±0.89	16.61±1.64	329.46±12.12	< DL

**Table (4.1) continued..**

<b>Town</b>	<b>Sample</b>	<b>U-238 series(Ra- 226)</b>	<b>Th232 series(Ra- 222)</b>	<b>K-40</b>	<b>Cs-137</b>
8-Halfa	S <sub>81</sub>	23.08±2.32	29.39±2.61	182.35±9.07	< DL
	S <sub>82</sub>	26.39±0.91	37.05±1.84	83.55±7.28	< DL
	S <sub>83</sub>	33.46±0.90	50.74±1.90	121.56±7.61	< DL

S: Sedements

- L D : Within the low limit of detection.

The average activity concentrations of  $^{226}\text{Ra}$  ( $^{238}\text{U}$ ) series measured by gamma spectrometry (GS) is  $22.31 \text{ Bqkg}^{-1}$  and the average activity concentrations of  $^{232}\text{Th}$  series measured by GS is  $25.24 \text{ Bqkg}^{-1}$  dry weight respectively, ranging from  $12.89 \text{ Bqkg}^{-1}$  in Sample  $S_{12}$  to  $33.46 \text{ Bqkg}^{-1}$  in Sample  $S_{83}$  for  $^{226}\text{Ra}$  and from  $16.61 \text{ Bqkg}^{-1}$  in Sample  $S_{73}$  to  $50.74 \text{ Bqkg}^{-1}$  in Sample  $S_{83}$  for  $^{232}\text{Th}$ .

From these results, it is shown that there is a small range of variation in the activity concentrations of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  along the River Nile. Also, the results show that the higher activities are presented in Halfa at northern Sudan and the lowest activities are presented at inbetween.

The average activity concentration of  $^{40}\text{K}$  is  $372.98 \text{ Bqkg}^{-1}$  dry weights, ranging from  $83.55 \text{ Bqkg}^{-1}$  in Sample  $S_{82}$  to  $533.27 \text{ Bqkg}^{-1}$  in Sample  $S_{61}$  the higher activities are presented in Wawa and the lowest activities are presented at Halfa. The activity concentration of  $^{137}\text{Cs}$  is less than deduction limit (<DL) The small variations in the concentrations of the investigated radionuclides along the River Nile could be explained by the following points, with the help of the mechanical analysis for the sediment samples :

- The radioactivity content in sediments increases with the increase in the organic matter content, as it has a large cation exchange capacity, and decreases with the increase in total carbonate ions which are particularly effective in forming soluble complexes [8,87].
- There is a positive correlation between clay and silt percentage and the radioactivity concentration in sediments, and a negative correlation between sand percentage and the radioactivity concentration in sediments [12]. The clay minerals are composed mainly of plate-like particles of secondary aluminium silicates which have a negative charged surface and so, they have the ability to

attract cations that can exchange with the cations adsorbed on the clay surface. This explains why most of the radionuclides in sediments and soils are adsorbed on clay and silt rather than on sand, because the specific activity of radionuclides decreases as the particle size increases [87,88].

- The variation in the activity concentration of  $^{40}\text{K}$  content in sediments is attributed to the variation in clay and silt, sand and organic matter percentages along the river.
- The very low concentration of  $^{137}\text{Cs}$  in sediments is mainly attributed to the global fall-out due to nuclear weapons testing and nuclear accident releases. This conclusion was based on the absence of the short-lived  $^{134}\text{Cs}$  ( $t_{1/2} = 2.06$  years).
- The uranium content of the sediment samples obtained by the Gamma spectrometry has been observed to display deficits. In fact, the gamma spectrometric study was based on the measurement of radon daughters ( $^{214}\text{Pb}$  and  $^{214}\text{Bi}$ ) assuming a state of secular radioactive equilibrium between them and  $^{226}\text{Ra}$ . But “all decay products of U-238 are in radioactive equilibrium with their precursors if not subjected to chemical or physical separation”. So, a considerable opportunities exist for the disequilibrium of uranium series radionuclides during the processes of disintegration and reconstitution of sediments and disturbing regular flood irrigation and plowing of the soils leading to a partial escape of radon gas because of the different mobilities and geochemical properties (leaching) of the radionuclides belonging to the  $^{238}\text{U}$  series, including the escape of  $^{222}\text{Rn}$ , since  $^{214}\text{Bi}$  and  $^{214}\text{Pb}$  were used to determine the  $^{226}\text{Ra}$  activity concentrations, and the secular equilibrium between  $^{238}\text{U}$  and its daughter  $^{226}\text{Ra}$  can only be obtained in closed systems (mother

rock). This is the reason for the observed slightly lower concentrations of  $^{238}\text{U}$  measured by GS [89].

The  $^{232}\text{Th} / ^{238}\text{U}$  ratio has a mean value of 1.13, this mean higher concentration of  $^{232}\text{Th}$  compared with that of  $^{238}\text{U}$  as shown in Table(4.2).

**Table (4.2) :** The  $^{232}\text{Th} / ^{238}\text{U}$  ratio

<b>NO</b>	<b>Sample</b>	<b>U-238 series(Ra-226)</b>	<b>Th232 series(Ra-222)</b>	<b><math>^{232}\text{Th} / ^{238}\text{U}</math> ratio</b>
1	S <sub>11</sub>	19.98±2.2	24.21±2.38	1.12
2	S <sub>12</sub>	12.89±2.35	21.39±2.62	1.66
3	S <sub>13</sub>	28.82±2.66	25.52±2.69	0.89
4	S <sub>21</sub>	28.52±1.73	31.89±1.70	1.12
5	S <sub>22</sub>	28.52±1.10	31.89±2.59	1.12
6	S <sub>23</sub>	25.74±2.31	32.38±2.87	1.26
7	S <sub>31</sub>	18.58±0.92	20.09±1.65	1.08
8	S <sub>32</sub>	19.78±0.90	22.23±1.97	1.12
9	S <sub>33</sub>	19.78±0.3	20.51±1.7	1.04
10	S <sub>41</sub>	21.72±2.54	21.67±2.37	1.00
11	S <sub>42</sub>	16.06±1.81	20.05±1.68	1.25
12	S <sub>43</sub>	17.28±3.05	20.67±2.30	1.20



13	S <sub>51</sub>	21.96±2.06	24.89±1.81	1.13
14	S <sub>52</sub>	24.97±1.00	25.50±1.80	1.02
15	S <sub>53</sub>	23.50±0.98	24.06±1.75	1.02
16	S <sub>61</sub>	21.80±3.07	23.53±2.70	1.08
17	S <sub>62</sub>	21.56±1.91	24.54±2.38	1.14
18	S <sub>63</sub>	19.51±0.88	17.53±1.57	0.90
19	S <sub>71</sub>	20.53±2.84	19.49±2.32	0.95
20	S <sub>72</sub>	21.54±2.01	19.92±1.98	0.92
21	S <sub>73</sub>	19.42±0.89	16.61±1.64	0.86
22	S <sub>81</sub>	23.08±2.32	29.39±2.61	1.27
23	S <sub>82</sub>	26.39±0.91	37.05±1.84	1.40
24	S <sub>83</sub>	33.46±0.90	50.74±1.90	1.52

The  $^{232}\text{Th} / ^{238}\text{U}$  ratio has a mean value of 1.13, this relative higher concentration of  $^{232}\text{Th}$  compared with that of  $^{238}\text{U}$  may be explained by the relatively greater geochemical mobility of  $^{238}\text{U}$  compared to  $^{232}\text{Th}$  [11]. In addition, it may also be explained by the fact that the  $^{232}\text{Th}$  content in sediments or soils increases more than other radionuclides with the increase in fine particles [87]. Which is observed for most sites in soils along the River Nile bank.

This work results is found to be in agreement with the results obtained for the average natural radioactivity levels in the Middle Egypt [88] , and Upper Egypt [20]. As represented in table (4.3)

**Table (4.3)** : Comparison of the average radioactivity levels (range) in the Northern Sudan (This Work), Middle Egypt and Upper Egypt

<b>Region</b>	<b>Concentration of Radionuclides in Bq/kg</b>	<b>Concentration of Radionuclides in Bq/kg</b>	<b>Concentration of Radionuclides in Bq/kg</b>
	<b>238U series</b>	<b>238U series</b>	<b>238U series</b>
Northern Sudan (This research)	22.31(12.89-33.46)	25.2416.61-50.74)	372.98(83.55-533.27)
Middle Egypt	17.00(10.10-37.00)	18.00(10.10-37.00)	354.00(199.80-599.00)
South Egypt	13.50(4.90-26.60)	14.0(4.60-37.70)	90.00(26.00-295.00)

#### 4.2.2 The Activity Concentration of Radionuclides in Water Samples

The activity concentration of radionuclides  $^{226}\text{Ra}$  of ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  in water samples has been measured using gamma spectrometry as represented in table (4.4) .

**Table (4.4)** The Gamma Activity of Radionuclides in water

NO	Town	Sample	U-238 series(Ra-226)	Th232 series(Ra-222)	K-40	Cs-137
1	Khartoum	W <sub>1</sub>	5.30±2.4	< DL	165.60±9.8	< DL
4	Atbara	W <sub>4</sub>	< DL	< DL	162.80±10.3	< DL
6	Wawa	W <sub>6</sub>	3.90±0.2	3.40±0.1	76.30±1.2	< DL
8	Halfa	W <sub>8</sub>	2.40±0.1	3.00±0.1	36.80±0.6	< DL

- W: Water
- L D: Within the low limit of detection.

The activity concentration of Radionuclides  $^{226}\text{Ra}$  ( $^{238}\text{U}$ ) series in sample W<sub>4</sub>, and  $^{232}\text{Th}$  series in samples W<sub>1</sub>,W<sub>4</sub> were within the low limit of detection

of the HPGe detector (0.7, 0.6 ) Bq/l respectively. Also the activity concentration of  $^{137}\text{Cs}$  within the low limit of detection of the HPGe detector ( 0.1 )  $\text{BqL}^{-1}$  respectively [68].The average activity concentration of  $^{40}\text{K}$  in water is  $110.38 \text{ BqL}^{-1}$ , with a range of (36.80-162.80)  $\text{BqL}^{-1}$  which is more than detection limit ( $2.99\text{BqL}^{-1}$ ) [91]. The higher activities are presented in Khartoum and the lowest activities are presented at Halfa . In general, the very low concentration of  $^{40}\text{K}$  in the Nile River water may be explained by the very low salinity and the high dilution factor for the river water (3 million  $\text{m}^3/\text{day}$ ) [68].

Results obtained did not show any anomalous value of nuclides  $^{226}\text{Ra}$  of ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  . There activities are similar to those given by data published for other regions in the world.

The gamma spectrometry was used is more suitable for sediment and soil samples than water samples.

## **4.3 Dose Assessment**

During the last period, worldwide attention has been directed towards the estimation of natural background radiation levels; the major contribution to the various radiation exposures received by man from the natural sources. The assessment of the radiation doses to human from natural sources is of special importance because, natural radiation is by far the largest contributor to the collective dose received by the world [42].

### **4.3.1 Absorbed Dose Rate in Air from External Gamma Radiation emitted by sediment samples**

The exposure dose rate at one meter above the ground from the natural radionuclides  $^{226}\text{Ra}$  ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series and  $^{40}\text{K}$  were calculated for the sediments samples using the formula (3.5) described in chapter 3. All the results are expressed in  $\text{nGyh}^{-1}$ , and represented in table (4.5) .

**Table (4.5):** The Absorbed dose rate from sediment samples

<b>NO</b>	<b>Town</b>	<b>Sample</b>	<b>Absorbed dose rate nGyh<sup>-1</sup></b>
1	Khartoum	S <sub>11</sub>	39.38
		S <sub>12</sub>	32.20
		S <sub>13</sub>	52.54
2	Aljaily	S <sub>21</sub>	47.52
		S <sub>22</sub>	48.49
		S <sub>23</sub>	53.76
3	Shandy	S <sub>31</sub>	35.30
		S <sub>32</sub>	37.91
		S <sub>33</sub>	37.18
4	Atbara	S <sub>41</sub>	43.70
		S <sub>42</sub>	32.64
		S <sub>43</sub>	41.47
5	Dongola	S <sub>51</sub>	40.91
		S <sub>52</sub>	43.60
		S <sub>53</sub>	41.98
6	Wawa	S <sub>61</sub>	39.76
		S <sub>62</sub>	46.62
		S <sub>63</sub>	34.72
7	Janas	S <sub>71</sub>	41.26
		S <sub>72</sub>	43.86
		S <sub>73</sub>	34.65
8	Halfa	S <sub>81</sub>	35.67
		S <sub>82</sub>	36.88
		S <sub>83</sub>	49.05

S: Sediments

The results obtained show that the average dose rate is 41.29 nGyh<sup>-1</sup> and typical range is (32.20-53.76) nGyh<sup>-1</sup>. The estimated dose rates from Sediments along the River Nile bank in northern Sudan are within the typical world range (24.0-160.0) nGyh<sup>-1</sup> [92], and they are in good agreement with the values estimated before for South Egypt[20], and Middle Egypt [88], as shown in table ( 4 .6).

**Table (4.6):** Comparison of the average absorbed dose rates for sediments samples from River Nile Branch in Upper Sudan , Middle Egypt and South Egypt

<b>NO</b>	<b>Region</b>	<b>Average (range) absorbed dose rate nGy/h</b>
1	River Nile Branch in Upper Sudan ( This research )	41.29 (32.20 - 53.76 )
2	River Nile Branch in Middle Egypt	34.40 ( 23.00 - 64.00 )
3	River Nile Branch in Upper Egypt	22.6 0 ( 7.10 - 49.40 )

#### **4.3.2 Effective dose rate from External Gamma Radiation emitted by sediment samples**

The Effective dose rate from the natural radionuclides <sup>226</sup>Ra (<sup>238</sup>U) series, <sup>232</sup>Th series and <sup>40</sup>K were calculated for the sediments samples using the formula (3.6) described in chapter 3. All the results are expressed in mSv y<sup>-1</sup>, and represented in table (4.7).

**Table (4.7):** The Effective dose rate from sediment samples

<b>NO</b>	<b>Town</b>	<b>Sample</b>	<b>Effective dose rate mSv y-1</b>
1	Khartoum	S <sub>11</sub>	0.19
		S <sub>12</sub>	0.16
		S <sub>13</sub>	0.26
2	Aljaily	S <sub>21</sub>	0.23
		S <sub>22</sub>	0.24
		S <sub>23</sub>	0.26
3	Shandy	S <sub>31</sub>	0.17
		S <sub>32</sub>	0.19
		S <sub>33</sub>	0.19
4	Atbara	S <sub>41</sub>	0.21
		S <sub>42</sub>	0.16
		S <sub>43</sub>	0.20
5	Dongola	S <sub>51</sub>	0.20
		S <sub>52</sub>	0.21
		S <sub>53</sub>	0.21
6	Wawa	S <sub>61</sub>	0.20
		S <sub>62</sub>	0.23
		S <sub>63</sub>	0.17
7	Janas	S <sub>71</sub>	0.20
		S <sub>72</sub>	0.22
		S <sub>73</sub>	0.17
8	Halfa	S <sub>81</sub>	0.18
		S <sub>82</sub>	0.18
		S <sub>83</sub>	0.24

S: Sediments



The results obtained for Effective dose rates from sediments along the River Nile bank in northern Sudan show that the average Effective dose rate is  $0.20 \text{ mSv y}^{-1}$  and typical range is  $(0.16 - 0.26) \text{ mSv y}^{-1}$ , and it is less than world maximum value ( $1 \text{ mSv y}^{-1}$ ) [25].

#### **4.3.3 Radium Equivalent Activity rate for External Gamma Radiation emitted by sediments samples**

In order to compare the specific activities of samples containing different amounts of  $^{226}\text{Ra}$  ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series and  $^{40}\text{K}$ , the radium equivalent was calculated using the formula (3.7) described in chapter 3. All the results are expressed in  $\text{Bq kg}^{-1}$ , and represented in table (4.8) .

The radium equivalent is related to the external gamma ray dose and internal dose due to radon and its daughter. The maximum radium equivalent values must be less than  $370.0 \text{ Bq/kg}$  for safety use [93].

**Table (4.8) : The Radium Equivalent Activity for sediments samples**

<b>NO</b>	<b>Town</b>	<b>Sample</b>	<b>Radium Equivalent Activity Bqkg<sup>-1</sup></b>
1	Khartoum	S <sub>11</sub>	82.91
		S <sub>12</sub>	69.52
		S <sub>13</sub>	105.70
2	Aljaily	S <sub>21</sub>	101.01
		S <sub>22</sub>	102.76
		S <sub>23</sub>	113.02
3	Shandy	S <sub>31</sub>	72.89
		S <sub>32</sub>	79.03
		S <sub>33</sub>	76.57
4	Atbara	S <sub>41</sub>	88.64
		S <sub>42</sub>	68.82
		S <sub>43</sub>	84.81
5	Dongola	S <sub>51</sub>	85.74
		S <sub>52</sub>	90.42
		S <sub>53</sub>	86.78
6	Wawa	S <sub>61</sub>	96.51
		S <sub>62</sub>	95.80
		S <sub>63</sub>	70.20
7	Janas	S <sub>71</sub>	83.05
		S <sub>72</sub>	87.83
		S <sub>73</sub>	68.54
8	Halfa	S <sub>81</sub>	79.15
		S <sub>82</sub>	85.80
		S <sub>83</sub>	115.38

S: Sediments

As shown in table (4-8), the average value for the radium equivalent is  $87.20 \text{ Bqkg}^{-1}$  and typical range is from  $68.54 \text{ Bqkg}^{-1}$  to  $115.38 \text{ Bqkg}^{-1}$ . The results is less than The maximum radium equivalent values ( $370.00$  )  $\text{Bqkg}^{-1}$  [93].

The twenty four measurements along the River Nile made it possible to draw a radiological map which shows a fluctuation of radium equivalent values from the middle Sudan(Khartoum) to northern Sudan( Halfa) of the River Nile bank.

#### **4.3.4 Absorbed Dose Rate in Air,Effective dose rate in Air and Radium Equivalent Activity from External Gamma Radiation emitted by water samples**

The Absorbed Dose Rate in Air, Effective dose rate in Air and Radium Equivalent Activity from the natural radionuclides  $^{226}\text{Ra}$  ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series and  $^{40}\text{K}$  were calculated for the Water samples using the formulas (3.5),(3.6) and (3.7) described in chapter 3.All the results are represented in table (4.9) .

**Table (4.9):** The Absorbed Dose Rate, The Effective dose rate and The Radium Equivalent Activity from water samples

<b>NO</b>	<b>Town</b>	<b>Sample</b>	<b>Absorbed dose rate</b>	<b>Effective dose rate</b>	<b>Radium Equivalent Activity</b>
1	Khartoum	W <sub>1</sub>	< DL	< DL	< DL
4	Atbara	W <sub>4</sub>	< DL	< DL	< DL
6	Wawa	W <sub>6</sub>	7.31	0.036	14.64
8	Halfa	W <sub>8</sub>	4.45	0.022	9.52

The activity concentration of Radionuclides in <sup>226</sup>Ra (<sup>238</sup>U) series in sample W<sub>4</sub>, and <sup>232</sup>Th series in samples W<sub>1</sub>, W<sub>4</sub> were within the low limit of detection of the HPGe detector (0.7, 0.6 ) BqL<sup>-1</sup> so we can't calculate the Absorbed Dose Rate, The Effective dose rate and The Radium Equivalent Activity for samples W<sub>1</sub> and W<sub>4</sub>.

For samples W<sub>6</sub> and W<sub>8</sub> all results obtained from calculation is less than world maximum value [25,92,93] .The level recommended by the World Health Organization for the effective dose due to water consumption is 0.1mSvy<sup>-1</sup> ~0.27μSvday<sup>-1</sup> [94].

#### 4.4 Conclusion

These results obtained for the radioactivity concentration in samples lead to the following concluded points :

1- The radioactivity content in sediments increases with the increase in the organic matter content, as it has a large cation exchange capacity, and decreases with the increase in total carbonate ions which are particularly effective in forming soluble complexes [8,87].

2- There is a positive correlation between clay and silt percentage and the radioactivity concentration in sediments, and a negative correlation between sand percentage and the radioactivity concentration in sediments [12]. The clay minerals are composed mainly of plate-like particles of secondary aluminium silicates which have a negative charged surface and so, they have the ability to attract cations that can exchange with the cations adsorbed on the clay surface. This explains why most of the radionuclides in sediments and soils are adsorbed on clay and silt rather than on sand, because the specific activity of radionuclides decreases as the particle size increases [87,88].

3- The reason for the observed slightly lower concentrations of  $^{238}\text{U}$  measured by GS is that secular equilibrium between  $^{238}\text{U}$  and its daughter  $^{226}\text{Ra}$  can only be obtained in closed systems [89]. All decay products of U-238 are in radioactive equilibrium with their precursors if not subjected to chemical or physical separation.

4- The higher concentration of  $^{232}\text{Th}$  compared with that of  $^{238}\text{U}$  may be explained by greater geochemical mobility of  $^{238}\text{U}$  compared to  $^{232}\text{Th}$  [11]. The  $^{232}\text{Th}$  content in soils increases more than other radionuclides with the increase in fine particles [87]. Which is observed for most sites in soils along the Nile .

5- The activity concentration of  $^{137}\text{Cs}$  depends on  $^{137}\text{Cs}$  accumulation in soil, soil type and the agricultural activity in the site. These factors affect the  $^{137}\text{Cs}$  deposition on soil, The low concentration of  $^{137}\text{Cs}$  in samples is mainly attributed to the short-lived  $^{134}\text{Cs}$  ( $t_{1/2} = 2.06$  years). so the activity concentration of  $^{137}\text{Cs}$  in soil samples is less than deduction limit [17, 73, 90].

6- The variation in the activity concentration of  $^{40}\text{K}$  content in sediments is attributed to the variation in clay and silt, sand and organic matter percentages along the river.

7- The very low concentration of  $^{40}\text{K}$  in the Nile River water may be explained by the very low salinity and the high dilution factor for the river water (3 million  $\text{m}^3/\text{day}$ ) [68].

8- The gamma spectrometry was used is more suitable for sediment and soil samples than water samples

9- The obtained results of the natural radionuclides are within the world typical ranges for  $^{238}\text{U}$  (10-50)  $\text{Bqkg}^{-1}$  ,  $^{232}\text{Th}$  (7-50)  $\text{Bqkg}^{-1}$  and  $^{40}\text{K}$  (100-700)  $\text{Bqkg}^{-1}$  dry weight respectively [2,3].

10- Results obtained did not show any anomalous value of nuclides  $^{226}\text{Ra}$  of ( $^{238}\text{U}$ ) series,  $^{232}\text{Th}$  series,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  . There activities are similar to those given by data published for other regions in the world.

11-The estimated Absorbed Dose Rate in Air, Effective dose rate in Air and Radium Equivalent Activity from External Gamma Radiation emitted by sediments and water samples along the River Nile bank in northern Sudan are less than world maximum value [25,92,93].

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