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RADIATION DOSE FROM NATURAL AND MANMADE RADIONUCLIDES IN THE SOIL OF NIAB, FAISALABAD, PAKISTAN

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Natural Radioactivity originates from extraterrestrial sources as well as from radioactive elements in the earth's crust. The amount of radioactivity in soil varies widely and is a source of continuous exposure to human beings. Amount of radioactivity in soil depends upon the type of soil and its uses. For the investigation of amount of radioactivity in the fertile soil, an area of about 100 hectares of land was selected in NIAB (Nuclear Institute for Agriculture and Biology) at Faisalabad, Pakistan. Soil samples were collected from the cultivated and fertilized land. Activity concentration was measured using a HPGe (high purity germanium) γ ray detector and a PC based MCA. Specific activity levels due to ^{40}K, ^{137}Cs, ^{226}Ra and ^{232}Th were determined in 125 fertilized soil samples collected at a spacing of about 4 hectares at the depth level of 0–25 cm with a step of 5 cm depth. Activity concentration of the concerned radionuclides for the NIAB soil is: ^{40}K, 614.4–670.7 Bqkg^{-1}; ^{137}Cs, 2.1–3.1 Bqkg^{-1}; ^{226}Ra, 28.6–32.6 Bqkg^{-1}; and ^{232}Th, 51.6–60.3 Bqkg^{-1}. Chemical analysis for concentration of Na, Ca and Mg was also carried out along with the measurement of electrical conductivity and pH of the soil samples. The absorbed dose in air at NIAB Farm is 75 nGyh^{-1} which is higher than the world average of 57 nGyh^{-1} but lies within the range (18-93) nGyh^{-1}.

Keywords: Fertilized soil; Environmental radioactivity; Gamma spectrometry; ^{40}K, ^{137}Cs, ^{226}Ra, ^{232}Th;

1. Introduction

The great interest expressed worldwide for the study of naturally occurring radiation and environmental radioactivity has led to the performance of extensive surveys in many countries of the world [1]. Such investigations can be useful for the assessment of public dose rates and the performance of epidemiological studies, as well as to keep reference data records, in order to ascertain possible changes in the environment radioactivity due to nuclear, industrial and other human activities [2]. Natural environmental radioactivity and the associated external exposure due to γ radiation depend primarily on the geological and geographical conditions, and appears at different levels in the soils of each region in the world [1]. The specific levels of terrestrial environmental radiation are related to the composition of each lithologically separated area, and to the content of the rock from which the soils originate [3]. Nuclear fission in connection with atomic weapons testing provides another source of soil contamination [4]. The fission product ^{137}Cs is strongly absorbed and retained by soil particles like the natural radionuclides, which are found randomly, distributed at different depths of soil [5]. The presence of radionuclides in soil is a source of radioactivity intake of human beings by direct and indirect ways. Due to increased public concern and awareness about radioactive pollution, this study has been carried out to measure the amount of radioactivity and assessment of radiation dose from the fertilized soils of NIAB (Nuclear Institute of Agriculture and Biology) at Faisalabad in the Punjab province of Pakistan.

The area under investigation consisted of 100 hectares of fertile soil at NIAB. The location of the area, as seen from Fig.1, is 31°24′ N and 73° 05′ E. The area is a part of natural unit known as the Indus Plain, which represent a vast geosynclines

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lying between the Himalayan foothills and center core of the Indian subcontinent. This depression which once may well have as offshoot of the sea, has been filled with tremendous quantities of sediments brought down by rivers from the Himalayas, and has consequently turned into an alluvial plain. In a few places this alluvium has been estimated to be several thousand feet thick. The rocks underlying the alluvium at great depth have no bearing on the soils. Although the entire area is an alluvial plain, different parts of the plain were deposited in different ways and at different times ranging from late Pleistocene to recent, as indicated by the degree of development of soils and elevation of land surface [6]. This area comprises the flat-topped river terrace, which is identified by the local people as the Sandal Bar. The second major land form is the Kamalia Plain. The courses of the rivers are winding and subject to the frequent alterations. In the rainy season, the water currents are very strong and often go in spate, inundating narrow belts of land on their flanks high floods, however, are of very short duration and pass in a few days. Unchecked seepage from the canals has considerably raised the water level.

The soil of Faisalabad is silt loam and very fine sandy loam having a weak subsoil structure with common kankers within five feet [6]. It is the fertile soil which belongs to the Indo-Gangetic Plain, that is a alluvial plain between the Himalayan Mountains and the central core of the Indian subcontinent. The alluvial deposit is generally more than a thousand feet thick and may extend down to several thousand feet at some places [6].

2. Experimental

2.1. *Soil sampling*

Soil sampling was carried out in the months of May–June in 2003. Sampling from the soil patches was done using the Standard Sampling Methods [7]. The area was divided into 25 sites of soil. The distance between every point was about 15–17 m. The sampling sites are also shown in Fig. 1 in the projection of the NIAB Farm. From each point (site), 5 samples were taken at a step of 5 cm depth covering 25 cm. In this way 25 points (sites) were covered and the total number of samples was 125. The samples were properly marked, cataloged and brought to Health Physics Laboratory at NIAB, Faisalabad, Pakistan for processing before analysis.

2.2. *Chemical analysis*

The chemical analysis of the soil samples was performed for the measurement of pH, electrical conductivity, and concentration of Ca, Mg, Na ions.

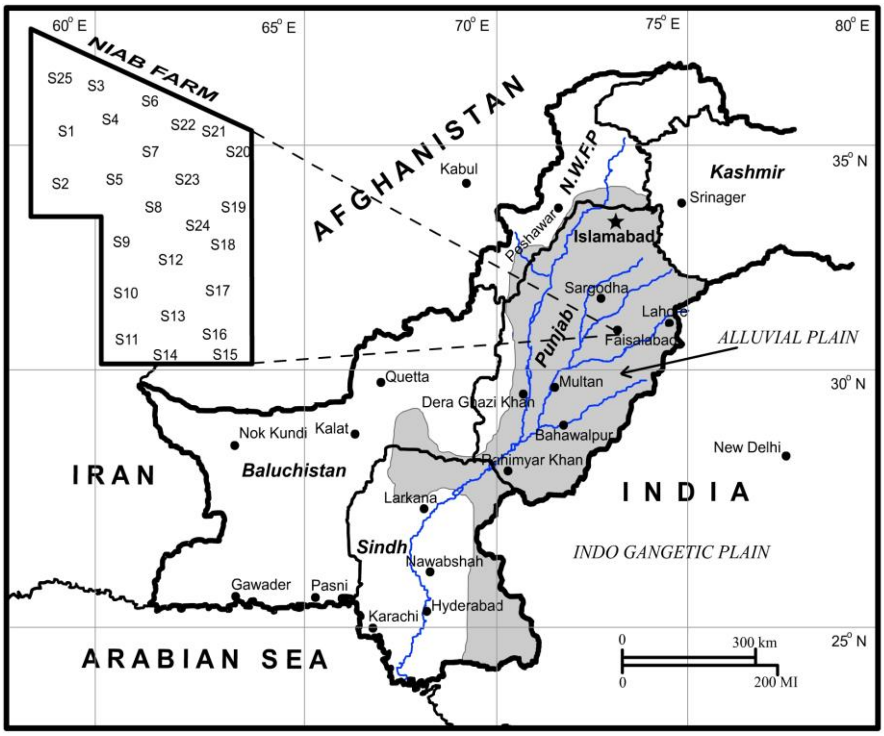

Figure 1. The map of Pakistan showing: (a) location of the area under study, (b) alluvial plain, and (c) location of sampling sites.

The methods are briefly described as follows:

The soil samples were checked for alkalinity and acidity by a pH meter, pH-530, W-T-W Germany. In this method a sensing glass electrode is inserted into extract of soil solution. The difference between H^+ ion activities in the wet soil and electrode gave rise to electrometric potential difference that was related to the pH of the soil solution.

The salt concentration of the soil was measured by a conductivity meter, LF-538 W-T-W, Germany. In this method the extract from a saturated soil solution gave an indication of salt level. Electrical conductivity (EC) was measured in μscm^{-1} at 28^oC.

The sodium and calcium plus concentration of various metal ions were determined by Flame Photometer, (PFP7, Jennway), and Titration technique. Flame Photometer, (PFP7 Jennway) technique was used for the determination of sodium contents in the soil samples. Titration technique was used to determine the Calcium and Magnesium concentrations. In this method 5 ml of extract of the soil sample is taken in a flask. Then buffer solution (Ammonium hydroxide+Ammonium Chloride) 10 drops and Erich Rome Black T 8.06 $meql^{-1}$ (2 drops) were added. The difference of initial and final reading of the indicator in the burette was taken, where the colour changed from red to blue.

2.3. Radiometric analysis

A high resolution spectroscopy system was used for the measurement of the energy spectrum of the emitted γ rays in the energy range between 50 and 3000 keV. The system consists of high purity germanium (HPGe) detector (coaxial cylinder of 55 mm in length) with an efficiency of 30%. The detector is mounted on a cryostat which is dipped into 30 liter nitrogen dewar. Experimental setup for spectra collection included the high-voltage detector bias supply, equipped with signal processing electronics consisting of a spectroscopy main amplifier and a multi-channel buffer which is a PC–based plug. For radiometric analysis, the collected soil samples were sieved through 0.2 mm mesh, hermetically sealed in standard 250 ml plastic Marinelli bottles, dry weighed and stored for more than 6 weeks prior to counting. The reference materials Soil-6 and RG1 set (obtained from IAEA) were also packed in plastic Marinelli bottles and stored for the same duration of time. This allowed establishment of secular equilibrium between ^{226}Ra and ^{222}Rn and its short lived decay products, although non-equilibrium is uncommon in rocks older than 10^6 years, and the ^{232}Th series may be considered in equilibrium in most geological environments [8]. In order to obtain a statistically small error (3-5%) for the γ ray peaks of interest, the reference material bottles were placed in front of shielded HPGe detector and measured for an accumulating time of 65000 s (~18 hours). The naturally occurring radionuclides considered in the present analysis of the measured γ ray spectra are: ^{214}Pb [241.9 (7.5), 295.2 (19.2), 351.9 (37.1) keV] , ^{214}Bi [609.3 (46.1), 1120.3 (15.0), 1764.5 (15.9) keV], ^{212}Pb [238.6 (43.6) keV], ^{212}Bi [727.2 (6.65) keV], ^{208}Tl [583.1 (30.9), 860.4 (4.3), 2614.6 (35.8) keV], ^{228}Ac [338.4 (12), 911.1 (29), 968.9 (17) keV)] and ^{40}K (1460.8 (10.7) keV]. Since secular equilibrium was reached between ^{232}Th and ^{238}U and their decay products, the concentration of ^{232}Th was determined from the average concentrations of ^{208}Tl, ^{212}Bi, ^{212}Pb and ^{228}Ac in the samples, and that of ^{238}U was determined from the average concentrations of the ^{214}Pb and ^{214}Bi decay products [2,9]. The measurement of ^{40}K concentration was based on single peak in the spectra.

Prior to samples and the standards measurements, the environmental γ ray background at the laboratory site was determined using an empty standard plastic bottle under the identical measurement conditions for counting time of 65000 s. It was later subtracted from the measured γ ray spectra of each sample and the standards.

The spectrometry system was calibrated for efficiency with the help of the IAEA reference materials Soil–6 and RG1–set. The efficiency calculations were performed using the software package GENI 2000. The detection efficiency on the system 'η' was plotted as a function of γ ray energy and is shown in Fig. 2. A polynomial of degree 2 was fitted on the experimental data and is given by the following relation:

$$\log \eta = 9.002 - 1.923\,(\log E) + 6.448\times10^{-2}\,(\log E)^2 \quad (1)$$

The lowest limits of detection (LLD) for ^{40}K (59 $Bqkg^{-1}$), ^{137}Cs (1.27 $Bqkg^{-1}$), ^{232}Th (3.31 $Bqkg^{-1}$) and ^{226}Ra (3.26 $Bqkg^{-1}$) were determined. Spectrum for every sample was collected for 65000 s , analysis was done with help of the computer software GENI 2000, and activity

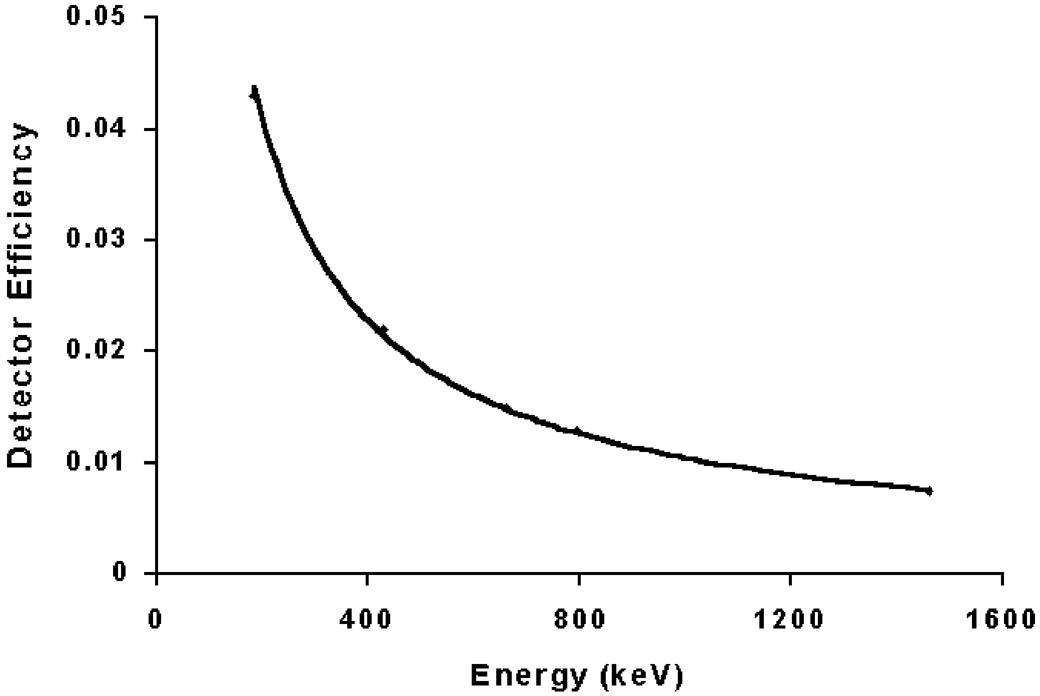

Figure 2. Efficiency of the detection system as a function of energy.

concentrations for ^{40}K, ^{137}Cs, ^{226}Ra and ^{232}Th were determined.

Since every sample was measured for 65000 s, therefore, spectrum of only one sample could be collected in a day. Background with empty bottle was measured at weekends and average of the background was subtracted from the spectra collected during that week.

Following the spectrum collection, activity per unit mass (activity concentration) for the detected nuclides was calculated from the count rates for every detected photo peak in the spectrum. The activity concentration, A (Bqkg^{-1}), of a radionuclide peak is given by [4]:

$$A = \frac{C \times 1000}{\eta \times y \times t \times m} \tag{2}$$

where $C = C_t - C_b$ = net peak counts, here C_t is the sample counts (peak area) and C_b is background counts for the respective peak; η= detection efficiency of the nuclide of peak energy; y= percent abundance (% yield); t= collection time (s), same for the sample and the background counts; m= mass of sample (gm); and the factor 1000 comes from mass conversion from gm to kg.

If, for the radionuclide considered, there are more than one peaks in the energy range of analysis (50–3000 keV), then the peak activities are averaged and the result is the weighted average nuclide activity. The total uncertainty of the radioactivity measurements, which is also applicable to the calculated γ dose and effective dose rates, was typically in the range 3–10%. It was calculated by taking into consideration the counting statistical error (3%) and other weighted systematic errors that mainly include the uncertainty in the efficiency calibration (0. 5–8%).

If naturally occurring radionuclides are uniformly distributed, dose rates, $\dot{D}$, at one meter above the ground surface in units of nGyh^{-1} can be calculated by using the fallowing formula:

$$\dot{D} = A \times C_f \tag{3}$$

where A is the activity concentration measured in Bqkg^{-1}, and C_f is the dose conversion factors in units of nGyh^{-1}per Bqkg^{-1} (absorbed dose rate in air per unit of activity concentration).

Table 1. Chemical analysis of the soil samples from NIAB, Faisalabad

Sampling Depth (cm)	Number of Samples	Electrical Conductivity (μscm^{-1})	pH	Concentration of Ca+Mg ($meql^{-1}$)	Concentration of Na ($meql^{-1}$)
0-5	25	3.1	7.7	1.6	32
5-10	25	2.5	7.8	2.2	26
10-15	25	3.1	7.7	1.6	27
15-20	25	3.3	7.6	1.7	26
20-25	25	4.3	7.7	1.6	28

3. Results and Discussion

The results of the chemical analyses of the soil samples under investigation are given in Table 1. The soil pH is perhaps the single most important aspect of soil chemistry. Strictly speaking, soil pH, or soil reaction is a measure of the number of hydrogen ions (^{+}H) present in a soil solution. In more common terms, it is a measure of alkalinity and acidity. The pH scale runs from 0–14 and 7 is for the neutral. Human activities that increase soil acidity include fertilization with ammonium containing fertilizers which ultimately enter the soil via rainfall. Irrigating with water having higher bicarbonates gradually increases soil pH and can lead to alkaline conditions. Slightly alkaline soil is not harmful to many plants. As seen from Table 1, the values are within 7.6 – 7.8 range, which shows that it is a slightly alkaline soil.

Electrical conductivity is a measure of salts present in the soils samples. On the upper soil surface 0–5 cm, the lowest value of electrical conductivity is 3.1 μscm^{-1} and highest equal to 4.3 μscm^{-1} at the depth of 20-25 cm (Table 1). It shows that due to regular irrigation the salts have been leached down. Calcium, magnesium and potassium are cation nutrients, meaning they are available to plants in a form with a positive charge, these nutrients adsorb to soil particles, especially clay particles. Soils high in clay or organic matter have cation exchange capacity (ECE). These soils act as reservoirs for these nutrients and plants growing in them seldom are deficient in the cation nutrients.

The measured values of concentrations of Na, Ca and Mg ions are also given in Table 1. The concentration values of Ca and Mg both lie in the range of 1.6–2.2 $meql^{-1}$. As it is a normal cultivated soil the concentration of sodium is of moderate value (26–32). The soil composition contains small but significant quantities of organic and inorganic compounds, which are essential for plant growth.

Rocks are radioactive due to naturally occurring radioactive material (NORM) in the earth's crust. The radioactivity of rocks ultimately shifts to soil. The levels due to terrestrial background radiation are related to the type of rock from which the soils originate [1]. Only the radionuclides with half-lives still comparable to the age of the earth and their decay products can be found today on the earth, e.g. ^{40}K, and ^{238}U and ^{232}Th series [10]. The manmade radioactivity as a result of nuclear explosions has also contaminated the earth's crust. Natural and manmade radioactivity was investigated in the soil of the area under study by mean of γ ray spectrometer. The natural radionuclides of interest are the ^{238}U and ^{232}Th series, ^{40}K and a manmade radionuclide, a fission product ^{137}Cs, which were determined in the fertilized soil of the Nuclear Institute for Agriculture and Biology (NIAB) in the city of Faisalabad in the Punjab province of Pakistan. The measured activity concentration of the radionuclides of concern is given in Table 2.

Activity levels were found to follow lognormal distribution. As regard of activity with respect to depth, no correlation was found between depth and measured radioactivity showing that natural radioactivity is randomly distributed in different depths of the soil under investigation.

The natural environmental higher levels of radiation are associated with igneous rocks, such as granite and lower level with sedimentary rocks [1]. The highest concentration of ^{40}K has been found in the sedimentary muddy material [10]. Potassium is an essential constituent for plant growth and is found in most of the soils, as

Table 2. Activity of naturally occurring radioisotopes in the cultivated/ fertilizedsoil samples from NIAB, Faisalabad, Pakistan

Sample Name	Depth from land surface (cm)	Number of Samples	Activity concentration (Bqkg^{-1})			
			^{40}K	^{232}Th	^{226}Ra	^{137}Cs
N1	0—5	25	642.6±22.0	58.0±2.1	31.4±1.3	3.1±0.4
N2	5—10	25	614.4±21.9	50.2±2.0	29.1±1.3	2.5±0.4
N3	10—15	25	629.8±22.0	51.6±2.0	28.6±1.3	2.7±0.4
N4	15—20	25	660.5±22.2	60.3±2.2	32.6±1.3	2.4±0.4
N5	20---5	25	670.7±22.2	55.8±2.1	29.1±1.3	2.1±0.4

potassium is present about 2.4% by weight on the earth crust [11], the concentration range of ^{40}K in the experimental soil was 614.4–670.7 Bqkg^{-1} with an average value of 642.6 Bqkg^{-1}.

Besides ^{40}K, the other naturally occurring radionuclides measured, were ^{226}Ra and ^{232}Th. Radium–226 (a member of ^{238}U series having half life of 1620 y) is considered as the highly radiotoxic natural radionuclide. The range of measured activity of ^{226}Ra in the fertile soil of NIAB was 28.6–32.6 Bqkg^{-1} with an average of 30.6 Bqkg^{-1}. The range of measured specific activity of ^{232}Th ($T_{1/2}$ = 1.4x10^{10} y) for the soil was 51.6–60.3 Bqkg^{-1} with an average of 55.8 Bqkg^{-1}. The average activity value of ^{232}Th is about two times higher than that of ^{226}Ra. The activity concentration of ^{40}K in soil is order of magnitude higher than that of ^{226}Ra and ^{232}Th for the fertilized soils.

It has been known since early in this century that phosphate rocks contain substantial concentration of uranium, thorium, radium, and their decay products [12]. Since phosphate rock is an important raw material used for the manufacturing of different types of phosphatic fertilizers, therefore, when this rock is processed into phosphatic fertilizers, most of the uranium and some of the radium accompanies the fertilizers [13]. It has also been estimated that phosphatic fertilizers applied to the agriculture fields in recommended amounts could raise radioactivity level in soils [14]. The greatest demand for potash has been in its use as fertilizer.

The activity of ^{137}Cs in all the samples was found to be 2.1–3.1 Bqkg^{-1} with the average value of 2.6 Bqkg^{-1}. Usually ^{137}Cs is not present in normal soils .The reasons of existence of ^{137}Cs in the soil of NIAB may be the fallout from nuclear tests carried out in the past and the reactor accidents such as the Chernobyl accident in 1986. The fission product ^{137}Cs is strongly absorbed and retained by soil particles, as are natural radionuclides which are randomly distributed at different depths of soil [5]. The comparison of the measured activity levels with that of the world mean level can be observed from Table 3. The variations in the activity levels have been observed to be lying within the activity values measured all over the world [4].

Table 3. Activity concentration levels in the soil of NIAB, Faisalabad, Pakistan in comparison with world range

Location	Activity concentration (Bqkg^{-1})			
	^{40}K	^{226}Ra	^{232}Th	^{137}Cs
NIAB soil Faisalabad.	614–671	28–33	51–60	2–3
World range [1]	140–850	17–60	11–64	0–35

The decay of radionuclides in soil produces a β–γ radiation fields in soil that cross the soil–air interface to produce exposures to humans [15]. External exposure outdoors arise from terrestrial radionuclides present at trace levels in all soils. The external γ dose rate in air is calculated from measurement of concentration of the relevant radionuclide in soil. In the UNSCEAR 2000 report, coefficients for conversion of activity concentration to absorbed dose rate in air are given which are reproduced here in Table 4. The absorbed dose rate was calculated by introducing the conversion coefficients in Eq.3 and the results are given in Table 5. The average value of dose rate is 75 nGyh^{-1} which lies between the dose rate range of 18–93 nGyh^{-1} and is greater than the mean value of 57 nGyh^{-1} given for the world in UNSCEAR report 2000.

Table 4. Activity to dose rate conversion factors [1].

Radionuclide	Dose coefficient (nGyh^{-1} per Bqkg^{-1})
^{40}K	0.0417
^{238}U	0.462
^{232}Th	0.604
^{137}Cs	0.1243

Table 5. Radiation absorbed dose rate in air due to natural radioactivity in the soil of NIAB, Faisalabad.

Radionuclides	Average Activity (Bqkg^{-1})	Absorbed dose in air (nGyh^{-1})
^{40}K	642.6	26.8
^{238}U	30.6	14.2
^{232}Th	55.8	33.7
^{137}Cs	2.6	0.3
	Total	75
World range [1]		57(18–93)

3.1. *Effective dose*

In order to assess the annual mean effective dose *'H'* in mSvy^{-1} to general public from outdoor terrestrial γ radiation the conversion factor and the dose calculation model given in UNSCEAR 2000 report was used as follows:

$$H = \dot{D} \times f \times T \times O \tag{4}$$

where $\dot{D}$ stands for dose rate in air (nGyh^{-1}), 'f' for dose to equivalent dose conversion factor (0.7 SvGy^{-1}), 'T' for time (8760 hy^{-1}), and 'O' for outdoor occupancy factor.

The time spent outdoors in the study area depends on the climate conditions. The climate of the area is semiarid subtropical continental and is characterize by the intense heat and cold winters. The mean annual air temperatures range between 13–25 ^{o}C for minimum and 20–38 ^{o}C for maximum. May and June are the hottest months and air temperature may be up to 47°C. January is the coldest month with a mean minimum of 3°C. Average annual rainfall is about 500 mm. About two thirds of the total annual precipitation is received during the monsoon season, which extends from the last days of June to mid September. October and November are the driest months. Keeping in view the atmospheric conditions of the area, the population of the area spends about 50% of the time outdoors. Therefore the value of the occupancy factor 'O' was taken to be 0.5 and the following simplified formula was applied for calculation of effective dose.

$$H = 3066 \times \dot{D} \tag{5}$$

The estimated annual mean effective dose comes out to be 0.23 mSvy^{-1}. It is not appropriate to compare the effective dose with the other countries of the world because climatic and atmospheric conditions; and living habits and cultural customs are not same thoroughout the world.

4. Conclusions

The chemical analyses of the samples under investigation show that the electrical conductivity increases with the depth because the salts have leached down due to irrigation. The amount of ^{232}Th is almost twice than that of ^{226}Ra present in the soils of NIAB, Faisalabad. The presence of ^{137}Cs in the soil of this area may be the nuclear fallout. The radiation dose rate in air from the radionuclides in soil of NIAB Farm is greater than the world average value but lies within the world range. The annual mean effective terrestrial radiation dose from NIAB area is 0.23 mSv.

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References

[1] UNSCEAR "Sources, effects and risks of ionization radiation", United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General assembly, with Annexes, New York (2000).

[2] M. Tufail, N. Ahmad, M.S. Zafer, M.S. Siddiqui, M.S. Sarwar, S. Ali and S. Almakly, The Arab. J. Sci. & Engg., **8** (1993) 353.

[3] C.S. Zahid, M.K. Hasan, M. Aslam, K. Khan, A. Jabbar and S. D. Orfi, The Nucleus, **36** (1999) 201.

[4] IAEA, "Measurement of radionuclides in food and environment", IAEA Technical Reports Series No. **295** (1989).

[5] C.S. Zahid, M.K. Hasan, M. Aslam, S. Iqbal, and S.D. Orfi, The Nucleus, **38** (2001) 101.

[6] WASID, “Soil Survey of Pakistan”, WAPDA, (1968).

[7] N.C. Brady, “The nature and properties of soils” (10th edition), Macmillan, London (1990) 243–246.

[8] N. Akhtar, M.A. Chaudhry, M. Tufail, M.M. Iqbal and S.D. Orfi, J. of Research (Science), Bahauddin Zakariya University, Multan, Pakistan, **14** (2003) 49.

[9] B.N. Hamid, M.I. Chowdhury, M.N. Aslam and M.N. Islam, Radiat. Protect. Dosim., **98** (2002) 227.

[10] UNSCEAR, “Sources, effects and risk of ionizing radiation”, United Nations Scientific Committee on Effects of Atomic Radiation, New York (1988).

[11] K. Khan, H.M. Khan, M. Tufail and N. Ahmad, Nucl. Sci. J., **34** (1997) 455.

[12] F. Habshi, “The recovery of uranium from phosphate rock: Progress and problems”, Proceeding of the 2nd International Congress on Phosphorus Compounds, Institute Mondial du phosphate, Paris (1980) 629-660.

[13] A. Hussain, J. Radioanal. Nucl. Chem., **188** (1994) 255.

[14] T.M. Bhatti and K.A. Malik, “Phosphate fertilizers a potential source for uranium recovery as by-product”, National Institute for Biotechnology & Genetic Engineering (NIBGE) Faisalabad, Technical Report No PAEC/NIBGE-2/1994.

[15] S. Selvasekarapandia, R. Sivakumar, N.M. Manikendan, V. Meenakshisundaram and V. Gajendran, Appl. Radiat. Isot., **52** (2000) 299.